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Survey of Irrigation in Eight Asian Nations

India, Pakistan, Indonesia, Thailand, Bangladesh, South Korea, Philippines, and Sri Lanka

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SURVEY OF IRRIGATION IN EIGHT ASIAN NATIONS: INDIA, PAKISTAN, INDONESIA, THAILAND, BANGLADESH, SOUTH KOREA, PHILIPPINES, AND SRI LANKA. William R. Gasser. International Economics Division, Economics and Statistics Service, U.S. Department of Agriculture. Foreign Agricultural Economic Report No. 165.

ABSTRACT

Most good land in the eight Asian nations surveyed is cropped, so large production increases will likely come from more intensive cultivation made possible by irrigation. Extension of irrigated areas and better water management could double production in some areas of India, Pakistan, Indonesia, Thailand, Bangladesh, South Korea, Philippines, and Sri Lanka. But, large investments will be required. This report reviews the current state of irrigation, plus prospects and plans, in these countries. Surface water will continue as the major irrigation source, although groundwater in India and Pakistan is gaining in importance.

Keywords: Asia, Developing nations, irrigation, water, input management, investment.

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SUMMARY

Large agricultural production increases are possible in all eight Asian countries surveyed in this report through extension of irrigated areas and better management of water resources. Large and continuous investment in irrigation will be required in these countries: India, Pakistan, Indonesia, Thailand, Bangladesh, South Korea, Philippines, and Sri Lanka.

Better information on the extent of the area requiring rehabilitation of existing irrigation and drainage works is needed to plan and budget programs to improve water use. Hydrological surveys need to be completed for all regions having irrigation potential. An effective extension service is needed to educate farmers in better water management. Policies relating to water charges to farmers need to be reviewed and adjusted to permit more efficient use.

The developing countries of Asia account for more than 60 percent of the arable irrigable area in the developing world (excluding People's Republic of China). Total harvested irrigated area in this region is more than 80 million hectares and may approach 140 million hectares by the year 2000, based on FAO estimates.

India, Pakistan, and Indonesia account for most of the irrigated area; India has more than 50 million hectares, Pakistan has 13 million hectares, and Indonesia has 6 million. The rest of the nations each have less than 3 million hectares under irrigation. Sri Lanka's 0.5 million irrigated hectares represent a third of its cultivated area.

Rice, the major cereal crop in this food deficit region, is the most suitable and highest yielding crop for the region's monsoon climate. Other major irrigated crops include wheat, sugarcane, and cotton.

Most good land in the area is cropped. Any significant cropland expansion can only be done on marginal lands, requiring large investments and strong erosion protection measures. But even this land is scarce. Hence, the emphasis is on more intensive utilization of existing arable land, largely through irrigation and better water managment. Irrigation, especially when accompanied by an appropriate package of inputs, not only increases yields but also provides greater stability in yields from year to year. New, high-yielding crop varieties require an assured water supply, in quantity and in timely application, as well as appropriate fertilizer use, in order to achieve their greatest potential.

Development of new irrigation schemes and rehabilitation or improvement of existing systems play an equally important role in the development of land and water resources. In some cases, as in Indonesia, returns from rehabilitation and improvement of existing systems are high compared with investment costs for new systems.

Development of large-scale irrigation schemes vs. minor projects (including wells) is controversial. Minor schemes often have a much lower investment per hectare irrigated and also usually have a much shorter gestation period. They frequently can make better use of the abundant labor resources in this region. Large-scale projects generally require a major central government role because of the capital requirements involved and the need to coordinate across village or provincial boundaries. The proposed national water grid in India, for example, involves interbasin transfer of water by interlinking various major rivers and transferring surplus flows to deficit areas. This mammoth 50-year project can only be undertaken through central government auspices.

Surface water will continue to be the major source for irrigation in most areas, although groundwater is gaining importance in some countries such as India and Pakistan. India's share of the irrigated area receiving its water supply from groundwater has increased from less than 30 percent in 1951 to more than 40 percent, as the number of tubewells increased sharply. Groundwater resources are generally cheaper than surface water irrigation in terms of initial investment but are more costly to operate because of pump fuel costs. Tubewells also provide greater control over timing of irrigation deliveries, a factor often more important than the quantity of water.

Surface water supplies vary considerably from season to season, with maximum flows during the monsoon season and minimum flows in the dry season when irrigation needs are greatest. Construction of storage capacity is needed to compensate for irregularities in seasonal flow. But, the terrain in such countries as Bangladesh is flat, limiting the number of sites suitable for storage reservoirs.

About 45 percent of the water in an unlined canal system is lost before ever reaching farmers' fields, and another 25 percent or more is wasted in the fields, according to one Indian study. Overall efficiency of water use may be about 50 percent, according to studies in Pakistan. Improper scheduling, delivery, and application of irrigation water contribute to inefficient use.

Very low charges for irrigation also cause inefficient water use. Farmers place a high value on water during shortages. At other times, however, the low cost of water along with the uncertainty when the next irrigation will be available means that farmers tend to take whatever water they can even if it exceeds requirements. The appropriate level of water charges or other taxes on irrigation benefits is important so that a balance is maintained between reasonable collections for benefits received and charges that may discourage farmers from participating in irrigation programs.

Another aspect of good water management involves removal of surplus water. Flooding, waterlogging, and salinity are major problems arising from surplus water. For example, 2.5 to 3.5 million hectares in Pakistan are estimated to have severe salinity problems, with another 2.5 to 4.5 million hectares moderately affected, a problem being addressed by that country's salinity control and reclamation projects. India's waterlogging problem is most serious in the Indus basin.

Primary barriers to water resource development will continue to be the availability and development of suitable groundwater resources and the lack of storage capacity for surface water, caused in part by lack of suitable sites and in part by the costs involved. Investment in development and improvement of irrigation facilities will likely continue to account for a major share of total investment in crop production.

Survey of Irrigation in Eight Asian Nations:

India, Pakistan, Indonesia, Thailand, Bangladesh, South Korea, Philippines, and Sri Lanka

William R. Gasser*

INTRODUCTION

Well-designed irrigation systems could double agricultural production in some developing areas of Asia, by expanding the arable area and by increasing yields on land already under cultivation. The success of fertilizer and high-yielding grain varieties often depends on a high level of water management made possible by irrigation.

This study reviews the status of irrigation, including future plans and prospects, in eight developing Asian countries: India, Pakistan, Indonesia, Thailand, Bangladesh, South Korea, the Philippines, and Sri Lanka. This survey can serve as a base for research and analysis of the agricultural potential of this food deficit region. The selection of countries was based on the present and prospective importance of irrigation in their agricultural sectors and on the fact that they represent a broad spectrum of economic and agricultural development. Some of the largest irrigation schemes in the world, outside of the People's Republic of China (PRC), are found in Pakistan and parts of India. At the other end of the scale, the island of Sri Lanka has fewer than 2 million hectares under cultivation, but almost a third of this area is irrigated. South Korea is an example of a developing country which has achieved significant economic development and where intensive land development has had a major role in the agricultural sector.

REVIEW OF SELECTED STUDIES

This section reviews irrigation-related studies prepared by the Food and Agriculture Organization (FAO) of the United Nations, the International Food Policy Research Institute, the International Rice Research Institute, and the Trilateral Commission.

Food and Agriculture Organization

FAO, as a part of its global study on Agriculture: Toward 2000, prepared a document on the regional implications for Asia. The region, comprising 15 developing countries, was grouped into four subregions: West and South Asia including Bangladesh,

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Burma, India, Nepal, Pakistan, and Sri Lanka; ASEAN (Association of Southeast Asian Nations) including Indonesia, Malaysia, Philippines, and Thailand; Indochina including Kampuchea, Laos, and Vietnam; and northern Asia including the Republic of Korea and the Democratic Republic of Korea. These countries account for 36 percent of the total arable land of developing countries, 62 percent of the arable irrigated area, and 32 percent of the arable rainfed land (60, 1,5). 1/ Implications of two scenarios were analyzed. The first was a trend scenario based on UN medium population projections, recent trends in gross domestic product (GDP) growth, and trend growth in production. This trend scenario attempted to identify emerging problems. The main or normative scenario postulated accelerated agricultural growth. The reference base period was 1974-76, with projections to 1990 and 2000 (60, 1).

The normative scenario postulated a substantial increase in the overall GDP growth rate in all regions except in northern Asia where the rate has already been relatively high. The regional rate of growth of gross value of agricultural production was projected to increase from 2.6 percent per year between 1961/65 and 1974/76 to 3.9 percent per year in 1980-90 and 3.5 percent per year during 1990-2000 (60, 7).

The study implicitly recognized that many of its projections were optimistic. The normative scenario assumed that:

> "Population growth assumptions remain the same as in the trend scenario. However, GDP growth rate is much higher, taking into account the provisional UN-wide assumptions, in keeping with aspirations for a new international economic order. The demands on agriculture resulting from population growth and higher GDP growth rate are set against the normative or maximum feasible [underscoring supplied] production growth."

The FAO document has a strong theme of self-sufficiency in food production with little discussion of the implications and pros and cons of such a policy for individual countries (60, 1).

Prospects for expanding arable land are limited, the FAO study noted. Increases in production, therefore, would have to come from increased intensity of land use and higher yields, especially the latter (60, 7).

1/ Underscored numbers in the parentheses refer to items in References section. The number(s) following the reference citation are page numbers in that reference.

Irrigation is the major factor that would contribute to increases in cropping intensity and yields, FAO stated. Net irrigated area for food production in the region was projected to increase from 72 million hectares in 1980 to 96 million hectares in 1990 and 117 million hectares in 2000, a more than 60-percent increase in 20 years (table 1) (60, 8).

Fertilizer use was projected to increase from about 8 million tons in 1980 to 25 million tons in 1990 and 48 million tons in 2000. The increase would be greatest in West and South Asia where present use is relatively low. Accelerated use of high-yielding varieties of crops combined with the fertilizer and irrigation increases would make yields, rather than area expansion, the dominant sources of cereal production gains (table 2) (60, 10).

The estimated required annual gross investment in crop production in FAO's normative scenario amounts to U.S. $13 billion in 1980, U.S. $17 billion in 1990, and U.S. $22 billion in 2000. This includes total gross investment in land development, including irrigation, of U.S. $7 billion in 1980, U.S. $8 billion in 1990, and U.S. $9 billion in 2000. The

Table 1--FAO normative scenario projections of irrigated area in Asia

Region	Irrigated area 1/			Irrigated area as a percentage of total harvested area		
	1980	1990	2000	1980	1990	2000
	--Million hectares--			--Percent--		
West and South Asia	55.3	74.4	91.9	29	36	42
ASEAN	12.6	16.2	19.0	25	28	30
Indochina	1.6	2.1	2.6	16	19	21
Northern Asia	2.7	3.2	3.4	42	62	67
Region 2/	72.3	95.8	116.9	28	34	38

1/ These figures appear to be net irrigated area and thus exclude multiple cropping.
2/ Table 6, p. 41, of the FAO study gave the harvested area in million hectares in the region as 284, 322, and 358, respectively, for 1980, 1990, and 2000. The irrigated areas as percentages of these figures are 25, 30, and 33, slightly lower than the percentages above, as given on page 10 of the document.
Source: (60, 10,42-3).

annual aggregate gross investment in the region (including both crop and livestock sectors) would increase from U.S. $22 billion in 1980 to U.S. $31 billion in 1990, and about U.S. $41 billion in 2000. The cumulative gross investment in the region between 1980-2000 would be approximately U.S. $620 billion (60, 20-1).

International Food Policy Research Institute

The International Food Policy Research Institute (IFPRI) published a report in 1979 analyzing the investment and input requirements for accelerating food production in low-income countries by 1990. Eight countries in Asia were included in the study: Bangladesh, Burma, India, Indonesia, Nepal, Pakistan, Philippines, and Sri Lanka (48, 26).

Total food production for the Asia region (in wheat equivalent on a caloric basis) in 1990 was projected at 324 million tons as a result of the investments proposed in the study. This is an increase of 137 million tons over the 1974-76 level of 187 million tons (about a 3.7-percent annual increase over the 15-year period). Almost three-fourths of this increase in production was projected to come from increases in production from irrigated areas, including new irrigation, improved irrigation systems, and improved yields on existing irrigation systems (48, 26).

Production potential in many countries is still underutilized. In monsoon Asia, where the supply of land is generally inelastic, there is still considerable opportunity to increase multiple cropping. Less than a third of the irrigation potential is being utilized in South Asia. In many areas equipped for irrigation, surface water is not being utilized fully or efficiently and groundwater exploration is only beginning (48, 43).

Table 2--Relative contributions of increases in area and yield to increased cereal production in Asia

Region	Percentage of cereal output from--			
	Harvested area		Yield	
	1980-90	1990-2000	1980-90	1990-2000
	Percent			
West and South Asia	18	12	82	88
ASEAN	43	54	57	46
Indochina	62	61	38	39
Northern Asia	14	0	86	100
Region	24	22	76	78

Source: (60, 42).

Three main approaches for developing agricultural production potential were identified: more intensive use of existing cultivated land through such measures as improved technology, improvements in existing irrigation systems, and drainage; expansion of the net irrigated area, such as converting rainfed land to irrigation; and expanding the net arable area under rainfed conditions. The first two approaches are becoming increasingly important in much of Asia as land expansion becomes more difficult. The authors pointed out that:

> ..."before investments in irrigation are made, consideration needs to be given to the potential provided by developing new irrigation systems and by improving existing ones, to the expected impact of irrigation on food production, and to the corresponding investments and operating costs of irrigation" (48, 44-7).

The projected growth rates for expansion in area equipped for irrigation were relatively modest in relation to 1964-74 trends. The increases in cropping intensity were expected to result from improved water supplies through irrigation thus permitting more double cropping, especially when crops with a shorter growing period are also introduced (table 3) (48, 48).

Almost three-fourths of the projected increase in Asian food production was expected to come from irrigated areas, both through expansion and improvements in irrigation and through substantial improvements in yields on such lands (table 4).

The capital cost of carrying out the proposed irrigation program in the Asia region would be approximately U.S. $46 billion (1975 prices). Eighty percent of this would be allocated for new irrigated areas, with the remaining 20

Table 3--Irrigation-equipped area, cropping intensity, and gross irrigated area in Asia

Item	Unit	1975	1990
Irrigation-equipped area	1,000 hectares	54,720	76,950
Cropping intensity 1/	Percent	122	136
Gross irrigated area	1,000 hectares	66,850	104,737

1/ Indicated by multiple cropping index (gross crop area divided by net crop area).
Source: (48, 49).

percent for improvements in existing irrigated areas. The authors pointed out that "irrigation projects usually succeed best when supported by institutions that optimize the interactions of people, land, water resources, technology, and inputs." Good water management practices frequently are as important as improvements in facilities (48, 60-1).

International Rice Research Institute

Lack of adequate water control is one of the overriding constraints to intensifying rice production and obtaining high rice yields in Asia, according to Herdt in an excellent analysis of some of the major economic issues relating to the efficient use of irrigation as a means of increasing agricultural production (29).

But, irrigation may be overstressed in development assistance policies, he said:

> "With the commitment of most development assistance agencies to agricultural and rural development, there is great

Table 4--Projected increases in food production from irrigated and rainfed land in Asia

Food production increase from--	Increase 1975-90	Percentage of total increase
	1,000 tons	Percent
Irrigated areas:		
New areas	48,785	36
Improved areas	25,416	19
1975 existing areas	25,649	19
Subtotal	99,850	73
Rainfed areas:		
Rainfed expansion	15,389	11
1975 existing rainfed area	21,681	16
Subtotal	37,070	27
Total increase	136,920	100
Total 1974-76 food production	187,020	--
Total 1990 food production	323,940	--

-- = Not applicable.
Source: (48, 86).

> pressure to lend money for agriculture, with irrigation receiving a disproportionate share. Irrigation projects attract development banks and aid agencies because they utilize large amounts of capital, result in highly visible infrastructure and provide a service that nearly everyone agrees is a requirement for development. At the same time, agencies charged with operating completed projects have many problems--difficulty in collecting water fees from farmers, difficulties in operating systems, shortages of water, and lack of community cooperation in maintaining systems, among others. Part of the reason for these difficulties may be that too many resources are made available for irrigation too quickly. As a result, the lack of 'absorbtive capacity' of irrigation agencies results in inefficient projects. Another reason for the difficulty is that the productivity of systems is often overestimated and the costs are often underestimated so the implementing agencies have unrealistic expectations about the financial payoffs.
>
> "At the same time, there are strong pressures within developing countries for continual expansion of irrigation systems. The desire for food self-sufficiency often overrides economic criteria on irrigation as well as other food production decisions...
>
> "Because the two institutions most closely associated with irrigation project preparation--the financing development banks and the irrigation authorities--have strong self interests in having favorable project evaluations, it is especially necessary for national planning agencies to be capable of carefully evaluating such projects and comparing them with alternative opportunities" (29, 1,2).

Herdt reported on analyses of growth in rice production in seven Asian countries that achieved annual growth rates in output greater than 2 percent during the late sixties and early seventies. These analyses indicated that irrigation was a major factor contributing to the increase in output (table 5).

Herdt's data show that expansion of irrigated land accounted for a substantial part of the output increases in a number of countries, but the importance of fertilizer as an accompanying essential input is also clearly evident. Residual yield gains, defined as those not attributable to fertilizer, probably include a considerable contribution from irrigation.

Herdt also reported on analyses by Herdt, Te, and Barker which examined prospects for Asian rice production and the investments needed to meet the Asian demand for rice in 1985. Irrigated land would have to increase at about 3 percent per year in order

for rice production to keep pace with demand. This is somewhat above the 2.4-percent rate registered from 1965 to 1970 and substantially above the 1.8-percent annual gains registered between 1970 and 1974. Recent irrigation increases in a number of Asian countries, however, have been substantial. Annual investment costs would have to be at least double the levels reached in the 15-year period from the early sixties to the midseventies (in real terms). They noted that these estimates "agree with the spirit of the Trilateral Commission report which estimated that $50 billion would have to be invested between now and 1993 in order to meet the rice requirements of Asia. The Trilateral Commission requirements are somewhat higher than our own, but this is due to somewhat different projections of demand." The authors' models also suggested that, aside from investments in irrigation and fertilizer, it would be necessary to raise the response to fertilizer above the present level being achieved by farmers through research, extension, and better quality irrigation. A balanced approach between investment in irrigation and other production increasing factors was emphasized (29, 20).

Trilateral Commission

A 1978 task force report to the Trilateral Commission analyzed the possibilities for increasing rice production in South and Southeast Asia. Rice accounts for almost three-fourths of food grain consumption in Asia, is the most suitable crop for the

Table 5--Relative contribution of area and yield in increasing rice output in Asia

Country	Period	Annual rate of production growth	Portion of growth attributed to--: Area: Irrigated	Area: Unirrigated	Yield: Fertilizer 1/	Yield: Residual 2/
		Percent	---- Percentage points ----			
Pakistan	1965-73	7.9	1.4	0	1.7	4.8
Malaysia	1965-73	5.7	3.7	.1	1.4	.5
Sri Lanka	1965-72	5.6	.5	.1	3.5	1.5
Indonesia	1962-72	4.8	2.2	-.3	1.1	1.8
Philippines	1965-73	3.4	1.2	-.3	1.5	1.0
India	1965-70	3.2	.6	.2	1.5	.9
Thailand	1965-72	2.1	.2	1.7	.3	-.1

1/ Calculated on the basis of 10-kilogram yield for every kilogram of fertilizer.
2/ Includes contribution to yield of improved average quality of land arising from a higher proportion of irrigated area.
Source: (29, 4).

region's monsoon climate, and is the highest yielding cereal. Productivity of rice in much of Asia is relatively low and, based on Japanese experience, has considerable potential for yield increases (15, XI-XII).

The authors stressed good water control as the "single most important factor in increasing paddy yield in Asia at this time." Irrigation, especially when accompanied by an appropriate package of inputs, not only increases yields but also provides greater stability in yields from year to year and also frequently makes double cropping possible (15, 24).

The study reported on some comparative cost-benefit analyses of various approaches for irrigation development. The lowest capital costs (U.S. $200) for increasing paddy production by 1 ton per hectare per year were obtained by improving inadequately irrigated land by such relatively simple measures as digging out and proper maintenance of farm ditches and good management of water supplies. The second lowest cost alternative (U.S. $300) involved introducing irrigation to rainfed cultivated land. The point was stressed that irrigation development need not necessarily require large capital investments and that approaches with high output-capital ratios that make use of the abundance of labor in much of Asia may well be the most appropriate technologies (15, 25-7).

The report proposed a 15-year international program for doubling rice production in South and Southeast Asia, focused on irrigation improvement as the leading factor in generating the production increases. Assuming that the demand for rice will increase by 3.4 percent annually (2.4 percent from population growth plus 1.0 percent from increases in per capita consumption), the study projected a demand for about 320 million tons of paddy by 1993, more than double the 1974 level. 2/ In order to meet this target, the irrigation rate (defined as total irrigated rice area harvested divided by total rice area harvested) for the region would have to increase from 38 percent in 1974 to 79 percent in 1993, with yields increasing to more than 4 tons per hectare. Using the lowest cost approaches, 30.4 million hectares of rainfed areas and 17.5 million hectares of inadequately irrigated areas would be converted to adequately irrigated areas during the 15-year period, 1978-1993. The total capital cost of this proposed program would be about U.S. $52.6 billion, at 1975 constant prices, including U.S. $7 billion for

2/ This 3.4-percent rate of increase is somewhat higher than the FAO study assumptions where the annual increase in cereal demand was assumed to be 3.2 percent for 1980-90 and 2.5 percent for 1990-2000. It is also higher than the 3-percent rate of growth assumed by Herdt, Te, and Barker.

conversion of inadequately irrigated land and $45.6 billion for conversion of rainfed land (15, 30-1).

INDIA

Irrigation and drainage are vital to Indian food production prospects. One study, cited in this section on India, projects a more than 50-million-ton increase in food production by 1990 resulting from investments in irrigation in that country.

Climate

India's climate is monsoon-tropical, with the Himalayas moderating the winter by blocking cold air masses from the north. The four seasons are the monsoon or rainy season in June-September; the season of the retreating southwest monsoon, October-November; the cold weather season in December-March; and the hot weather season in April-May (2, 4).

India's average annual rainfall is more than 1,100 millimeters, but there is tremendous variability from region to region. Variability is also high during the individual months but for the country as a whole the variability from year to year is relatively small. Regional fluctuation from year to year is so great, however, that annual rainfall can drop to half or a quarter of the average in bad drought years. Mean annual rainfall is highest along the southwestern coast and in northern Assam and lowest in west Rajasthan in the Thar Desert. The mean annual rainfall at Cherrapunji in the Assam hills is 11,735 millimeters and only about 250 millimeters in the Thar Desert. The coefficient of variation is lowest in northern Assam and highest for the subdivisions of Saurashtra and Kutch in Gujarat (25, 129; 49, 245).

A. M. Michael gave a good description of the monsoons, cyclonic depressions, and local storms which contribute rainfall in different degrees in various regions of the country and whose occurrence spell the difference between crop abundance or failure (43, 13).

Surface Water

Precise estimates of surface water flows are not possible in the absence of long-term and reliable measurements. Most recent estimates are based on a combination of actual measurements and empirical studies involving statistical correlation of runoff with rainfall and temperature. The Central Water and Power Commission of India placed the total average annual surface flow above 1,800 billion cubic meters (m^3) (37, 146).

Surface water flow in India depends on four major sources: direct runoff from rainfall; snow and glacial melting; flow in streams generated from groundwater; and inflow by water from upstream basins in the neighboring Pakistan, Nepal, and Tibet through the Indus, Ganges, and Brahmaputra River systems.

Inflow from neighboring countries accounts for about 200 billion m^3 of the total 1,800 billion m^3, with Nepal being the major source (14, 476; 43, 5).

India's rivers are scattered around the country, except for the northwest region. Those emanating from the Himalayas depend heavily on snow and glacial melting while those in the central and south are primarily monsoon-fed and hence their flow tends to be more irregular. K.L. Rao estimated that the 14 major rivers contribute about 85 percent of the total average annual surface water flow. 3/ An estimated 80 percent of India's population is located in these major river basins. Three of these rivers lie north of the Tropic of Cancer (23.5° latitude), seven lie between the Tropic of Cancer and 20° latitude, and four are in peninsular India. The 44 medium rivers (19 flowing west, 21 flowing east, and 4 flowing into other countries) contribute another 7 percent of the total flow, and the minor rivers (including desert rivers) account for the remaining 8 percent (54, 47,55).

An estimated 80 to 85 percent of the total average annual river flow occurs in the 3 to 4 monsoon months, which demonstrates why storage is so important for Indian agriculture. In the midseventies, the total storage capacity, built or under construction, was about 160 billion m^3, including about 15 billion m^3 storage in tanks and small ponds. Ultimately, this storage capacity is projected to more than double, perhaps to 350 billion m^3. Also, on full development of the nation's water resources, another estimated 450 billion m^3 of water may be used through diversion works or direct pumping, 4/ with the remaining 1,000 billion m^3 or more going on to the sea or neighboring countries (54, 57,60; 46, 378).

Estimated utilization of surface water flow in 1974 (at the end of the fourth 5-year plan) was about 250 billion m^3, with 100 billion m^3 from storage in reservoirs and tanks (total storage of about 150 billion m^3, with a third evaporation loss), and 150 billion m^3 from river and stream flow. Irrigation accounted for almost all--240 billion m^3. By comparison, about 95 billion m^3 were utilized in 1951, at the beginning of the first 5-year plan; again, almost all for irrigation. Nag and Kathpalia estimated that surface water utilization in the year 2000 would total about 500 billion m^3, including 420 billion m^3 for irrigation (46, 377-8; 45, 233).

3/ Major rivers have a catchment area greater than 20,000 sq. km.; medium, between 2,000 to 20,000 sq. km.; and minor, less than 2,000 sq. km.

4/ Present use through this source is probably somewhat more than a third of this amount.

A reasonable estimate of surface water resources potentially available for various purposes is 700 billion m^3 (table 6). 5/ There are varying degrees of topographical, geological, and technological constraints affecting the present and potential utilization of the different rivers. The narrowness of the Brahmaputra River Valley limits construction of storage capacity. Even with some diversion to the neighboring Ganges River, probably no more than 10 percent of the Brahmaputra's flow can be utilized. Probably no more than half of the flow in the Ganges River can be used. For the other 12 major rivers, perhaps 80 percent of the average annual flow can be used. Only 50 percent of the flow in the medium and minor rivers can be used because of the difficulty in locating appropriate sites for adequate storage. Under these assumptions, and further assuming some interbasin transfer of water, these estimates imply a potential utilization of about 800 billion m^3 of surface water (46, 378; 54, 217).

The importance of the technical and economic feasibility of interbasin transfer of water appears in the range of estimates given by A.K. Chandrashekhar. He estimated that the surface water potential can be anywhere between 650 and 800 billion m^3 and stated:

> "The main point at issue is how much of the annual flows of the Brahmaputra system and the west-flowing rivers of the Western Ghats chain of mountains are utilizable. The basic problem to be tackled is essentially an engineering one. In the case of the Brahmaputra system, the problem is one of linking it with the Indo-Gangetic river system and conveying its excess flows to the arid and sub-humid western Indian plains. In the case of the west-flowing rivers of the Western Ghats, the problem is one of transferring the excess flows from the western to the eastern side of the range to feed the east-flowing rivers and thus irrigate the semi-arid Deccan and Southern Plateaus and Plains regions" (14, 477).

The estimate of 700 billion m^3 given in table 6 was reported by Nag and Kathpalia of the Indian National Commission on Agriculture and Varma of the Central Board of Irrigation and Power. Nag and Kathpalia estimated that this potential would be utilized by the year 2025. Of this 700 billion m^3, an estimated 250 billion m^3 would come from storage in reservoirs and tanks (total storage of 350 billion m^3, but 100 billion lost by evaporation), and the remaining 450 billion

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5/ Estimates range from as low as 500 billion m^3 to 800 billion m^3 for potentially utilizable surface water. A part of this range depends on the extent to which the authors felt that interbasin transfer of water is technically and economically feasible.

Table 6--Indian water resource use

Water source/use	Ultimate potential	1973/74
	Billion m^3	
Surface water	700	250
Irrigation	510	240
Other uses	190	10
Groundwater	350	130
Irrigation	260	110
Other uses	90	20
Total water use	1,050	380
Irrigation	770	350
Other uses	280	30

Sources: (46, 377-8; 61, 75).

m^3 from flow in streams and rivers. Of the 700 billion m^3 used by 2025, an estimated 510 billion m^3 would be used for irrigation and 190 billion m^3 would go for other uses, such as domestic and livestock use, industries, and thermal power (61, 75; 46, 378).

Groundwater

Accurate estimates of groundwater resources are perhaps even more difficult to obtain than for surface water. Measurements of water balance, annual recharge, and groundwater levels have to be maintained. Systematic hydrogeological surveys had been carried out in about a third of India by 1975 (17, 1).

Part of the difference in estimates of groundwater resources probably arises from problems of definition. Groundwater can be divided broadly into two parts: usable, that quantity which is replenishable and economically exploitable; and static, the balance which is not economically exploitable to be used every year. Rao and Ramesan further defined groundwater potential as follows: replenishable reserve, or the average annual replenishment from rains (most groundwater estimates appear to be based on this definition); secular storage, or groundwater available down to a given depth, say 300 to 600 meters beyond the zone of water table fluctuations; induced recharge, or the additional usable reserve obtainable through proper management techniques with known technology; and potential reserve, that which can be created with construction of new underground reservoirs, using nuclear techniques or other future technology. These authors estimated that secular storage might approach 11,000 billion m^3, but they emphasized that only a

very small fraction can be utilized. For example, in times of extreme drought, some of these reserves can be used and then be allowed to recuperate in subsequent periods. Such withdrawal in excess of recharge is permissible provided that the withdrawals and recharge tend to balance out over the years. Induced recharge involves, for example, lowering the water table by pumping just prior to the beginning of the monsoon season to make room for intake of more water into groundwater reservoirs during the monsoon season. Rao and Ramesan estimated that, at least in some parts of India, the water table can be lowered by perhaps 2 meters with no deleterious effects, possibly creating an additional reserve of some 170 billion m^3 for each 1-meter lowering of the water table. They warned, however, that this procedure presents some potential danger in the event of 2 or more consecutive dry years, which would not permit appropriate recharge. The concept of potential reserves involves use of futuristic techniques to create huge underground reservoirs where rainfall now wasted during the monsoon season could be stored with minimal losses from evaporation (54, 103; 53, n.p.).

The National Commission on Agriculture estimated in 1976 that the potentially utilizable groundwater resources may be 350 billion m^3. Other estimates of usable potential range from about 255 billion m^3 to more than 370 billion m^3 (61, 75; 54, 104; 24, 408).

The rate of recharge of the groundwater supply depends on several factors such as total precipitation and soil porosity. Temperature and topography also affect recharge through evaporation and runoff, respectively. Chandrashekhar noted that the distribution of groundwater resources roughly coincides with the distribution of precipitation, suggesting that precipitation is the principal determinant of groundwater recharge. But, there is less fluctuation in groundwater supply than in precipitation because of the buffering effect of underground storage. This fact is important in arid and semiarid regions where precipitation variability is the greatest (14, 475).

Groundwater is exploited through three types of wells: dug, or open, wells, up to 15 meters depth; shallow tubewells, up to 90 meters depth; and deep tubewells, up to and beyond 300 meters. In 1974, dug wells accounted for almost two-thirds of the utilization, with shallow tubewells next in importance, and deep tubewells accounting for less than 2 percent of the total. Groundwater resources are generally cheaper than surface irrigation in terms of initial investment, but are more costly to operate because of fuel costs for operating pumps (54, 113; 43, 45; 14, 476).

An Indian farmer checks his irrigation tubewell (World Bank photo by J. Breitenbach).

Estimated utilization of groundwater in 1973/74 at the end of the fourth 5-year plan totaled some 120 to 130 billion m^3, with more than 80 percent used for irrigation. By early 1979, groundwater use probably had increased to about 170 billion m^3, compared with 65 billion m^3 in 1951 at the beginning of the planning periods. About 29 percent of the irrigated area was irrigated from groundwater in 1951; by the midseventies, this percentage had increased to more than 40 percent (43, 45; 2, 33).

Nag and Kathpalia projected near full development of water resources by 2025; they arrived at their estimate of 350 billion m^3 of potentially usable groundwater as follows. Of the estimated 2,150 billion m^3 that percolate into the soil annually on the average, about 1,650 billion m^3 would remain in the upper soil moisture layers generally accesssible to plants. The remaining 500 billion m^3 would go to groundwater, to which would be added 100 billion m^3 from streams and 250 billion m^3 from irrigation, making a total replenishable groundwater supply of 850 billion m^3. They estimated extraction for use would be about 350 billion m^3, with most of the remainder returned to the surface as regenerated flow into rivers and streams. Irrigation would use about 260 billion m^3, or almost three-fourths of the total utilization of 350 billion m^3 (46, 378).

Nag and Kathpalia estimated that in the midseventies an average of 6,500 m^3 of groundwater were used to irrigate 1 hectare, with 9,000 m^3 of surface water required, giving an average of about 8,000 m^3 per hectare. 6/ They projected more efficient use of water by 2025, reducing the irrigation requirement per hectare to about 7,000 m^3. Therefore, they projected that 110 million hectares can be irrigated using the 770 billion m^3 they projected to be available for irrigation: 510 billion m^3 of surface water and 260 billion m^3 of groundwater (table 6) (46, 378-9).

Groundwater resources of India are not well distributed geographically. Densely populated valleys of the Indus, Ganges, and Brahmaputra Rivers are said to have good groundwater resources: the alluvial plains of Punjab, Uttar Pradesh, Bihar, and West Bengal. More than 70 percent of groundwater development will have to take place in these basins. The Rajasthan region and the Deccan plateau are areas where availability is extremely limited (24, 410; 55, 32).

6/ Conveyance losses are higher for surface water and, since it is less costly than groundwater, more surface water tends to be wasted.

Irrigation Methods and Cropping Patterns

Cultivators in India in the midseventies obtained about 39 percent of their irrigation water from canals, another 42 percent from wells, 12 percent from reservoirs, and the remaining 7 percent from other sources (2, 33).

The share of the irrigated area receiving its supply of water from groundwater has steadily increased over the years, from about 29 percent in 1951 to more than 40 percent in the midseventies. Tubewells have supplied an increasing share of this groundwater, with growth in private tubewells being exceptionally rapid. The number of private tubewells rose from an estimated 93,000 in 1965/66 to 1.7 million by 1977/78. Government-owned tubewells expanded from 12,000 to 30,000 during this period. The number of open wells (where water is drawn by hand or animal) also increased, from 5.1 million in 1965/66 to 7.4 million by 1977/78; but, with increasing use of tubewells, the share of groundwater supplied by open wells declined (2, 33).

Indian irrigation statistics divided the source of surface water into major, medium, and minor projects. 7/ The share of the total irrigated area supplied by major and medium projects has remained fairly constant at slightly less than 45 percent of the total irrigated area. But with the increasing importance of groundwater, the share of the total irrigated area supplied by minor surface water projects has declined, although the absolute area has increased marginally, by slightly more than 1 million hectares since 1951 (62).

In the major agricultural area of the Indus, Ganges, and Brahmaputra basins in the north, about two-fifths of the area is irrigated, with surface water supplying almost 60 percent of the area, according to Rao. By contrast, 12 percent of the area is irrigated in the rest of the north, with groundwater supplying more than 80 percent (table 7).

Sprinkler irrigation has only very minimal use, less than 40,000 hectares in the midseventies, and is used primarily for high value crops such as tea, coffee, and those from orchards (34, 12; 54, 113).

There is not complete agreement among sources, or even within sources, as to the extent of irrigation in India. Part of the problem is definitional. For example, the distinction between

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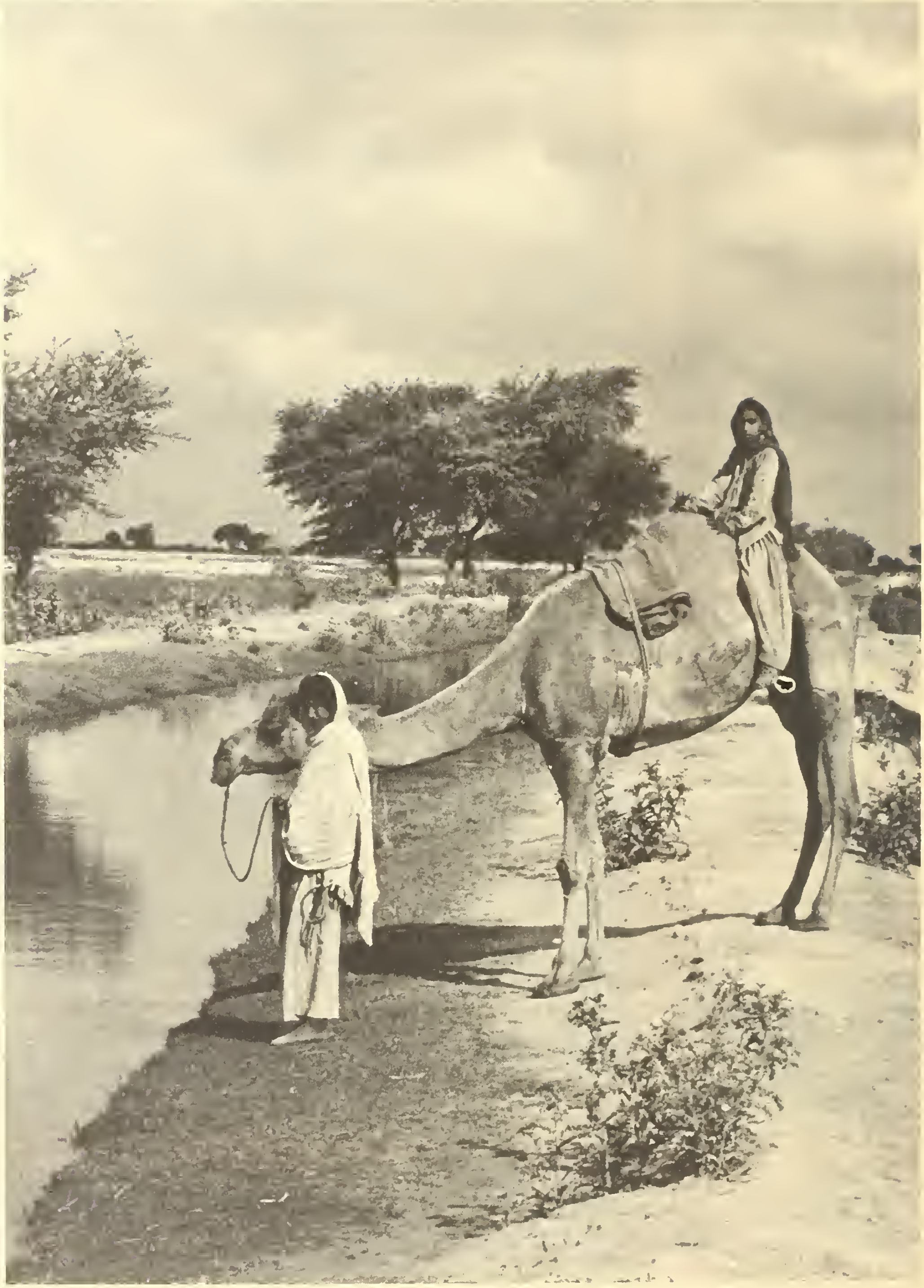
7/ Major projects are those costing more than 50 million rupees (U.S. $6 million); medium costing between 50 million and 2.5 million rupees (U.S. $0.3 million); and minor, costing less than 2.5 million rupees (43, 23).



A canal bringing irrigation water to farming area, India (FAO photo).

area actually used for irrigation in a given year and the area that is potentially usable that year but for one reason or another might not have been fully used is not clear. In many irrigation projects, especially the larger ones, the area actually irrigated is substantially less than the potential created by the irrigation system because of inefficiences in water conveyance. In recent years, net irrigated area figures have averaged somewhat more than three-fourths of the gross irrigated area. To put the data in table 8 into context, gross and net sown areas during the latter part of the seventies averaged about 170 and 142 million hectares, respectively. The irrigated area, thus, is approximately a fourth of the total sown area (32, 44).

The percentage of net irrigated area to cultivated area is the highest in the Indus basin (Punjab), Ganges basin (Haryana and Uttar Pradesh), and Cauvery basin (Tamil Nadu). The Punjab percentage of net irrigated area to net cultivated area is 75 to 80 percent, as contrasted with about 10 percent or less in Madhya Pradesh and Maharashtra (23, II-13).

Crop water requirements are influenced by evapotranspiration and vary by crop. There are also regional differences,

Table 7--Area cultivated and irrigated in India, early seventies

Region	Portion of gross cultivated area in India	Portion of area irrigated	Portion of area supplied by--	
			Surface water	Groundwater
	Percent			
North of Tropic of Cancer:				
Indus, Ganges, and Brahmaputra basins	44	37	58	42
Luni and other desert rivers and rivers of Kutch and Saurashtra	9	12	18	82
Central (20° to Tropic of Cancer)	14	16	69	31
South (below 20° lat.)	33	23	62	38

Source: (54, 114).

Table 8--Gross irrigated area in India 1/

Year	Area irrigated
	Million hectares
1950/51	22.60
1955/56	25.06
1960/61	27.89
1965/66	32.21
1968/69	35.93
1973/74 2/	42.30
1974/75 2/	43.65
1975/76 2/	45.30
1976/77 2/	47.38
1977/78 2/	49.50
1978/79	51.00
1982/83 (target)	62.30
Ultimate potential	113.00

1/ Estimates are given for the end of each planning period and for each year from 1974/75 to 1978/79.
2/ The estimates for these years (from source 23) were 2 to 4 million hectares higher than those given in another Indian source (32, 44). The reason for the differences was not given.
Sources: (16, 53,57; 23, II-93; 2, 29,33; 62).

depending on soil type. Rice, a major irrigated food grain crop, requires large amounts of water (table 9). Estimates by Punjab Agricultural University indicate that, for the same quantity of water, wheat produces three times as much as paddy: 12 to 13 kilograms of wheat per millimeter of water used, versus 3 to 4 kilograms of rice (44, 60).

About 15 million hectares of rice were irrigated in the midseventies, almost 40 percent of the total rice area. Wheat irrigated area was about 13 million hectares, around three-fifths of the total wheat area (table 10). Irrigated area of food grains (including pulses) was about 34 million hectares, or slightly more than a fourth of the total food grain area. Almost a fourth of the cotton area was irrigated, but four-fifths of the sugarcane area was irrigated. Because of the much higher yields on irrigated land, half of total crop production comes from irrigated land. Probably 80 percent

Table 9--Water requirements for selected crops in India

Crop	Water requirement
	Millimeters
Rice	1,200 to 1,800
Wheat	200 to 500
Corn	500 to 800
Sorghum	500 to 700
Sugarcane	1,400 to 2,500
Cotton	500 to 700
Groundnuts	600

Sources: (54, 120; 14, 477).

Table 10--Irrigated crop areas as percentages of total harvested area and gross irrigated area in India

Crop	1950/51	1960/61	1970/71	1975/76
	Percent			
Irrigated area as portion of total harvested area:				
Rice	32.0	36.7	38.1	38.2
Wheat	34.9	32.7	54.4	61.9
Pulses	9.4	8.0	8.8	8.0
Total food grains (incl. pulses)	18.8	19.1	24.2	26.5
Sugarcane	67.3	69.3	72.4	81.0
Total oilseeds	NA	3.3	7.4	NA
Cotton	8.2	12.7	17.3	23.0
Irrigated area as portion of gross irrigated area:				
Rice	43.8	44.7	37.5	33.2
Wheat	15.1	15.1	26.0	27.9
Pulses	8.6	6.8	5.3	4.3
Total food grains (incl. pulses)	81.2	78.9	78.8	75.2
Sugarcane	5.2	6.0	4.9	4.9
Total oilseeds	NA	1.5	2.9	NA
Cotton	2.0	3.4	3.6	3.7

NA = Not available.
Sources: (2, tables 6, 11; 23, II-16,17,93; 31, 38-9,42-3).

or more of wheat production comes from irrigated areas (2, 18, table 11; 42, 306).

Multiple cropping (two or more harvests per year) is steadily increasing in India. The gross sown area in the late seventies averaged about 170 million hectares, against a net cropped area of approximately 142 million hectares (a multiple cropping index--gross crop area divided by net crop area--of about 120). The multiple cropping index in 1951/52 was about 112. The current plan projects an increase in the multiple cropped area to almost 38 million hectares by 1982/83, but does not envisage much increase in the net cropped area (2, 29; 23, II-2).

The bulk of the recent increase in food grain output has been generated by increased use of inputs. India's National Commission on Agriculture (NCA) has adopted some input/output relationships to give an approximate measure of the relative effects of various inputs. These relationships recognize the interaction among inputs and the influence of other factors, notably weather. But, beyond the interactions and other influences, the input/output relationships do provide rough estimates of the effects of each input. The NCA relationships indicate that: adding 1 hectare to food grain cropped area adds 0.45 tons to food grain production; adding irrigation to 1 hectare adds an additional 0.5 tons; applying 1 nutrient ton of fertilizer to food grain crops adds 10 tons to production; a shift of 1 hectare from pulse and coarse grain cropping to either rice or wheat adds 0.33 tons to production (62).

The area planted to high-yielding varieties (HYV) tends to be closely associated with increases in irrigation and fertilizer. Wheat production rose sharply in the late sixties with the introduction of high-yielding varieties, reflecting increases in area and yields. After this initial burst in expansion of HYV wheat area, growth proceeded more slowly. About 70 percent of the wheat area is now planted with high-yielding varieties. Irrigation, particularly from private tubewells, was a primary factor in this expansion of wheat grown in the dry rabi season. The new varieties made irrigation investment more profitable (42, 50; 62).

HYV rice area grew less rapidly than the HYV wheat area, but nonetheless there has been a steady spread of HYV rice as new locally suitable varieties have been developed and rice cropping has spread into areas such as Punjab and Haryana. Farmers there are familiar with the advantages of such varieties and have adequate irrigation facilities to provide water control (62).

Flooding and Waterlogging

Flooding is a major problem in India, possibly affecting 20 million hectares. The flood problem is particularly severe in

the Brahmaputra and lower Ganges River basins in the states of Assam, Bihar, Uttar Pradesh, and West Bengal, as well as in the delta areas of Andhra Pradesh and Orissa. Floods affected about 7 million hectares annually in the 1953-72 period. Direct damage was estimated at 1.5 billion rupees (U.S. $0.3 billion). About 70 percent of this was crop damage (45, 235; 30, 24).

About a third of the 20 million hectares subject to flooding has already been protected. Ultimately, 16 million hectares out of the 20 million probably can be reasonably protected (30, 24).

An average of 0.3 to 0.4 billion rupees (U.S. $40 million to $53 million) (constant 1970/71 prices) were spent annually on flood control measures in the fourth and fifth plan periods (1969/70-1977/78). This annual expenditure is projected to increase to almost 1 billion rupees (U.S. $130 million) in the current plan period (1978/79-1982/83) (62).

There are other irrigation problems. Large tracts of land suffer from waterlogging because of inadequate drainage. Drainage problems frequently develop as a consequence of irrigation, caused by such factors as heavy seepage from unlined canals. Another cause is the tendency of some farmers to apply too much water and, in some cases, the need to use large amounts of water to leach undesirable salts from the crop root zone. About 6 to 7 million hectares are affected by waterlogging and associated problems of salinity and alkalinity (45, 236; 54, 120).

Waterlogging is most serious in the Indus basin and, to a smaller extent, in the Ganges basin, especially in the states of Punjab and Haryana. Waterlogging problems are not always caused by excessive watering or poor drainage. Low-lying areas near rivers often get waterlogged during flooding, especially if they have no provisions for proper drainage. And, water tables in many coastal delta areas are high due to tidal influence. Large-scale drainage improvements have been undertaken in the states of Punjab, Haryana, and West Bengal, but much remains to be done. Plans for irrigation systems must provide for adequate drainage (54, 120; 45, 236).

Water Management and Pricing

Water losses by seepage and evaporation are a major problem in irrigation. The Indian Central Water and Power Commission estimated that about 45 percent of the water in an unlined canal system is lost before ever reaching farmers' fields and that perhaps another 25 percent or more is wasted in the fields. A. M. Michael estimated a farm-level efficiency of 43 percent in surface water utilization and 70 percent in groundwater utilization. He assumed that possibly by 1990 the efficiencies can be improved to slightly above 60 percent and 80 percent,

Surface salt caused by bad drainage and waterlogging in irrigated field in India (FAO photo by D. Mason).

respectively, for surface and groundwater utilization. Other sources are somewhat less optimistic, suggesting an achievable overall efficiency under Indian conditions of about 60 percent (34, 11; 43, 49,50; 62).

> S.P. Mukerji, in a 1979 article on irrigation management, stated: "The most important and difficult part of irrigation management in developing countries is that of determining and enforcing the most productive and equitable manner of distributing water...and evolving and executing a cropping pattern most suited to that pattern of water distribution. Unless this can be done and discipline of water distribution adopted by the cultivators collectively with individual freedom to choose the cropping pattern most economical for the water availability, irrigation may be counterproductive economically as well as socially" (44, 60).

Proper allocation and scheduling of irrigation water and adoption and enforcement of rules and regulations governing access to water by farmers are major problems. Bromley, Taylor, and Parker described several ways in which unreliable water deliveries can adversely affect production. For example, farmers with insecure water supplies tend to use lower levels of inputs as a hedge against reduced input response during possible periods of water scarcity. Farmers sometimes tend to spread scarce canal water supplies over "larger than optimum" areas, while in other cases farmers tend to overirrigate their land as a means of reserving water supplies in case of later delays in water delivery. These authors noted that farmers whose fields are most distant from the source of water frequently have the least secure water supplies, and that farmers with large holdings and other forms of economic power tend to have more secure water supplies (13, 370-2).

Collective action through water users' associations is one way farmers might gain better control over the amount and timing of water delivery. Such sharing projects are underway in Andhra Pradesh, Maharastra, Gujarat, and Uttar Pradesh. A well-defined system of water sharing is being implemented, whereby each farmer's rights to the complete flow of water from the lowest irrigation outlet is specified and then enforced by an organization of farmers using that outlet. The period of access is proportional to the land area and each farmer knows when his turn comes each week. The group pressure of farmers seems to be adequate to overcome the obvious problem of the farmers closest to the outlet, or those with the most local influence, depriving others of their water rights (62).

Irrigation charges are not uniform among states in India. They generally comprise one or more of the following elements: a

water rate, depending on the kind and extent of the crop; an increment in land revenue based on increased benefit derived annually from providing irrigation facilities; a betterment levy, representing the government's share in the increase in land value accruing with the provision of irrigation facilities; and an irrigation cess, or tax, in the form of an annual charge per hectare of irrigable area, whether water is actually taken for irrigation or not, to be adjusted in the water rate when the facility is used (16, 372).

Water rates have not been related either to the cost of supplying water nor to the quantity of water supplied. Charges based on the volume of water supplied are being considered in order to discourage excessive water use. But, this procedure presents some difficulties because of the numerous small landholdings involved. Experience on state-owned tubewells, where the volumetric system of rates is used, has shown that the water depths are much less than where rates are charged on an area basis (45, 237).

Some states, as a promotional measure, charge lower rates in areas where irrigation is first being introduced to encourage farmers to change their cropping system. As irrigation agriculture becomes more familiar, the rates are raised, perhaps in 2 or 3 years (16, 382).

There is criticism that water rates and the betterment levy have not brought as much revenue as expected, and that the betterment levy has been a "myth." The main obstacle in enforcing the betterment levy laws has been the difficulty in assessing the increase in the value of land as a result of irrigation. Dakshinamurti, Michael, and Mohan noted that:

> "...the tenancy laws and land reforms and regulations on transfer of landed properties to prevent fragmentation of holdings have all affected the market value of land. Hence, the assessment of the portion of the increase in the price of land due to irrigation alone has become difficult. The Irrigation Commission has... recommended that the existing Acts on betterment levy be suitably amended so that half the capital cost of the irrigation projects is recovered from the beneficiaries. It was further suggested that the recovery of the levy should start three years after irrigation is provided in an area and it should be spread over a long period, but not exceeding 30 years, in order to reduce the burden on farmers" (16, 383).

Investment in Irrigation

Public investment in Indian irrigation totaled approximately 73 billion rupees (U.S. $13 billion) (current prices) from the beginning of the first 5-year plan (1950/51) through the fifth

plan (1977/78). Almost three-fourths was spent on major and medium surface water projects, with the remainder on minor projects, including groundwater. 8/ The share of minor projects in total investment on irrigation increased from about 15 percent in the first plan to 20 percent in the second, 32 percent in the third, and to more than 40 percent in the three annual plans 1966/67-1968/69, primarily reflecting sharply increased investment in groundwater projects. Part of this spurt in groundwater development in the late sixties was attributed to liberalization of institutional credit facilities. In the fourth plan period, the share of minor projects in total irrigation investment dropped to 30 percent, and declined further to about 23 percent in the fifth plan ending in 1977/78. A further decline is projected in the draft of the current plan (ending in 1982/83) (62; 40, 29).

The largest investments over the years have taken place in the Ganges, Krishna, Indus, and Godavari basins, especially in the states of Uttar Pradesh, Andhra Pradesh, Maharashtra, Bihar, and Karnataka (54, 117; 52, 90). Average annual outlays for irrigation for each of the plan periods show a steady increase even when expressed in terms of constant 1970/71 prices (table 11).

The outlay on irrigation in the first plan period was about 19 percent of the country's total outlay for all sectors of the economy, but in subsequent periods has been between 10 to 12 percent, increasing to about 13 percent in the current plan period (62).

Opponents of large projects have argued that such projects often require large public investment in selected places that benefit relatively few people. Minor irrigation schemes generally involve lower investment costs per hectare. Proponents of the latter have contended that their overall economics are also favorable, after taking into account such factors as depreciation and operating expenses. They have also claimed that the time gap between creation and utilization of potential is substantially less for minor works than for major and medium projects. Actual irrigated areas in many of these larger projects are substantially less than the potential created by the irrigation system, because of inefficiencies in water supply. The effect of this underutilization is to greatly

8/ See footnote 7 for definitions. Major and medium projects are based on surface water utilization. Minor projects include small surface water schemes like tanks, direct lifting/diversion from streams, and groundwater development through open and tube wells (45, 233).

An Indian farmer works on a field irrigation ditch (FAO photo by F. Mattioli).

Table 11--Average annual Indian outlays for irrigation

Plan and period	Annual outlay
	Billion rupees 1/
First, 1951/52-1955/56	1.59
Second, 1956/57-1960/61	1.79
Third, 1961/62-1965/66	2.55
Annual, 1966/67-1968/69	2.88
Fourth, 1969/70-1973/74	3.07
Fifth, 1974/75-1977/78	4.47
Current revised plan (1978/79-1982/83)	8.74 (projected)

1/ Rs. 1.00 = U.S. $0.133.
Source: (62).

increase the cost per hectare actually irrigated, compared with the planned cost based on the full potential (52, 39, 40; 62).

Barker discussed three forms of irrigation development--tubewells, communal irrigation systems, and national systems--and concluded that particular situations dictate which form of capital investment is best. For example, substantial public investment is required in large river deltas before private or communal investments can become profitable. But, substitution of community labor for public investment could make fuller use of existing labor and reduce costs of irrigation development (7, 16).

Plans and Prospects

Nag and Kathpalia indicated that full development of water resources will likely not be achieved until the year 2025, with ultimate utilization of 1,050 billion m^3, including 700 billion m^3 of surface water and 350 billion m^3 of groundwater. Total utilization was around 400 billion m^3 in the midseventies and is projected to increase to about 750 billion m^3 by 2000 (46, 381).

Irrigation is the major water use and will remain so, but its share of total use will probably decline from about 90 percent at present to less than three-fourths of the total upon full utilization of water resources. Domestic and livestock uses, and especially industries and thermal power, are expected to take an increasing share of water resources. Nag and Kathpalia projected an irrigation potential by the year 2025 of about 110

million hectares, utilizing 770 billion m^3 of water (510 billion m^3 of surface water and 260 billion m^3 of groundwater). Other Indian irrigation officials have projected that 113 million hectares can ultimately be irrigated (46, 379,381; 2, 33).

All estimates of potentially usable water supply, and accompanying estimates of potentially irrigated area, include some provision for interbasin transfer of water because of the uneven geographic distribution of water resources. River flow and underground resources in the region north of the Tropic of Cancer account for nearly two-thirds of India's water resources, Rao estimated. Much of the balance is groundwater and flow of medium and minor rivers. He estimated that half of the water in the coastal medium and minor rivers cannot be utilized and hence judged that the water available in the country south of the Tropic of Cancer may be only a fourth of the total usable supply. There is generally a water surplus in the north and a deficit in the south and west. A national water grid has been proposed to interlink the various major rivers and transfer the surplus flows to areas of deficit supply. A United Nations Development Program (UNDP) mission conducted studies on the feasibility of the grid in 1971-72; the report endorsed the concept. The grid is intended to link the natural rivers together by a system of canals (54, 218-9).

Two main groups of transfer links are proposed: one group extending from east to west and the other from north to southwest and south. When fully developed, the grid would comprise the following links: a Ganges-Cauvery link between the Ganges in the north and the Cauvery in the south; a Brahmaputra-Ganges link; a canal from the Narmada to Gujarat and western Rajasthan; a canal from the Chambal to central Rajasthan; a canal from the Mahanadi to the coastal areas in the east (Orissa and Andhra Pradesh); and links from the rivers west of the Western Ghats mountains to the drier eastern side (22, 100).

The grid would draw on both river water and groundwater; it is proposed that the water flow in some portions be reversible according to the season of the year. Plans call for use of surface water to replenish depleted groundwater supplies. The Ganges plains have considerable potential for groundwater storage. Significant storage also is expected in Gujarat and in the sandstone beneath Rajasthan. The proposed grid is a mammoth project, completion of which is in proposed phases over the next 50 years (22, 100-2; 14, 487).

The 1979 International Food Policy Research Institute report suggesting three main approaches for developing agricultural production potential was reviewed on p. 5. The expansion of

the rainfed net arable area approach is limited for India, but the expansion of irrigated area and intensification of cultivation approaches have significant potential for India (48, 44).

The IFPRI study examined the potential increase in food production that could be created by developing new irrigation systems and improving existing ones and the corresponding increases in investment and operating costs to provide this additional irrigation. Based on estimates by the Indian National Commission on Agriculture, the study projected almost a two-thirds increase in the gross irrigated area of India from 1975 to 1990, reaching about 69 million hectares. Almost a 10-percent increase in the cropping intensity was also projected because the number of crops grown in a year can be increased when the land is irrigated. The study projected that 80 percent of the area improved by irrigation investment (including both new areas and improvements) would be allocated to food production. Improvement of existing irrigation systems offers significant potential for increasing food production rapidly. But, it is difficult to get good information on the extent of the area requiring rehabilitation. The effect of irrigation on food production also is difficult to assess precisely (48, 49,52).

Recognizing these difficulties, the study projected more than a 50-million-ton increase in food production by 1990 resulting from investment in irrigation. 9/ About two-thirds of this amount would be from new irrigation and the remainder from improvements in existing irrigation facilities. Yields on which these projections are based assume proper irrigation management and fertilizer at recommended dosages. These improved yields also account for an additional 16-million-ton increase in production from the area already irrigated in 1975, giving a total increase in production from irrigated areas of an estimated 68 million tons. Expansion in rainfed area and accompanying yield increases over the entire rainfed area add another 14 million tons. Thus, the total food increase is an estimated 82 million tons above the 1974-76 level of 119 million tons, bringing the projected 1990 food production level to slightly more than 200 million tons. 9/ If the goals outlined above could be achieved, with the substantial contribution from irrigation, India should be able to maintain 1975 per capita consumption by 1990, and perhaps increase it marginally (48, 54,86).

9/ Food production data for the various crops were all expressed in wheat equivalent, based on caloric content.

Total capital investment in irrigation required to achieve the food production increases noted above would be almost $34 billion, more than 80 percent of which would be spent on new irrigation. 10/ The IFPRI authors noted that it was impossible to make an economic evaluation of the proposed investment in the countries covered in the study, but found that rates of return vary widely among projects. For example, projects involving construction of field channels in areas of eastern India have yielded a three-digit internal rate of return (48, 58,60).

A. Lahiri estimated that full development of groundwater irrigation potential would require about 61 billion rupees (U.S. $8 billion) and that projected surface water development would require an additional 75 billion rupees (U.S. $10 billion) in 1970 prices. He estimated that net domestic capital formation between 1970 and 2000 would range from 2,816 billion rupees (U.S. $375 billion) under low growth to 4,849 billion rupees (U.S. $645 billion) under high growth, also in 1970 prices. Thus, he projected that irrigation development would call for about 3 to 5 percent of net domestic capital formation over this period. Outlays on irrigation projects have declined to 10 to 13 percent of total budget outlays in recent plan periods. Lahiri projected that such a reduction in the share going to irrigation is reasonable (40, 28).

Based on a currency conversion of Rs. 1.00 = U.S. $0.12 to $0.13, Lahiri's estimate is significantly lower than the IFPRI estimate. However, his estimate of the share of irrigation development in total budgetary outlays may be too low.

PAKISTAN

Close to 90 percent of Pakistan's agricultural production comes from fields under irrigation. Most of the irrigation-generated food production increases in the next 10 years will likely come from improvements to existing irrigation facilities, according to one study.

Climate

Pakistan has a relatively dry climate with hot summers and cool winters. Average annual precipitation is less than 300 millimeters, ranging from almost 900 millimeters in the Karokaram range in the northeast to about 130 millimeters in the Baluchistan plateau. About 70 percent of the annual rainfall falls in the summer monsoon season from June to September. Most

10/ The capital investment for new irrigation is estimated at about U.S. $2,000 per hectare, including possible drainage expenses; investment for major and minor improvements are estimated at U.S. $700 and U.S. $300, respectively, per hectare. All IFPRI report references to dollars indicate U.S. dollars at 1975 prices (48, 58).

A field worker in India irrigates a field of potatoes (International Development Assoc. photo by M. Hill).

of the remainder of the annual precipitation comes in the winter rainfall season from December to March, with essentially no precipitation during the spring and autumn. Precipitation over the Indus plains is generally less than 500 millimeters and in the center of the plains is substantially less. Because of this relatively low rainfall and the subtropical-arid to semiarid climate, supplemental water supplies are needed to support an extensive agricultural system (25, 179; 10, 391; 35, 1).

Surface Water

The Indus River and its tributaries comprise a tremendous water basin and have been described as the greatest single system of irrigation in the world.

The 1960 Indus Waters Treaty resolved the dispute between Pakistan and India over sharing the waters of the river and its tributaries. It was agreed that, after a transition period, India would obtain the use of the three main eastern Indus tributaries--the Ravi, Beas, and Sutlej Rivers--while Pakistan would have the use of the western rivers--the Indus, Jhelum, and Chenab (25, 180).

The average annual discharge of these western rivers was estimated at about 175 billion m^3, including 115 billion from the Indus (including the Kabul River), 28 billion from the Jhelum, and 32 billion from the Chenab. The median combined flow (exceeded in 50 percent of the years) is only slightly less (almost 173 billion m^3), with the Indus River flow being somewhat less variable than the other two rivers (24, 799).

This mean annual discharge of about 175 billion m^3 is a reasonable estimate of available surface water. A World Bank study estimated that, by the midseventies, about 75 to 80 billion m^3 of this total was being diverted into the canals in the kharif season and about 35 to 40 billion m^3 in the rabi season (24, 799; 62). 11/

Of the 175 billion m^3 of water available in the Indus River system annually, about 113 billion m^3 are diverted into the canal systems of the Punjab and the Sind (the two provinces which contain almost all of Pakistan's irrigated area), according to Johnson, Early, and Lowdermilk. 12/ A UN conference report on water development and management gave a

11/ Kharif is the summer growing season and main rainy period, April to September; rabi is the winter growing season, October to March.

12/ They estimated that almost 36 billion m^3 are lost in the main canal and distributory system before entering the watercourse channel.

substantially higher estimate of 138 billion m^3 withdrawal for irrigation in 1975 (with also a slightly higher estimate of 183 billion m^3 for annual surface runoff) (35, 2; 10, 392-3).

The surface water supply available at the watercourse head regulators in 1975 was estimated at slightly over 80 billion m^3 (55 billion m^3 in the kharif season and 25 billion m^3 in the rabi season). This supply was projected to increase by 1980 to 89 billion m^3 (58 billion m^3 in kharif and 31 billion m^3 in rabi). A further increase by 1985 to 93 billion m^3 was projected (61 billion m^3 in kharif and 32 billion m^3 in rabi) (62).

In order to increase the water flow in the rabi growing season, two large dam projects were undertaken to conserve water in the storage reservoirs. The Mangla dam across the Jhelum River, completed in 1967, has an effective storage capacity of about 6.5 billion m^3. This reservoir was slated to replace loss of flows from the Ravi, Beas, and Sutlej Rivers under the Indus Waters Treaty. This storage more than doubles the rabi flow in the Jhelum River compared to the former mean, unregulated flow and permits the flow to increase at the time of planting wheat in Punjab in October and November. The reservoir also reduces flood damage (62).

Commissioning of the Tarbela dam across the Indus River provided an additional 11.5 billion m^3 of storage, part of which will be available for release in the rabi season or early or late kharif. This supply of water assures more timely water supplies in the critical sowing season and prevents sharp, damaging cuts in water supply during the rabi season. With this assurance of a more stable water supply, farmers may be more willing to use fertilizer and other yield increasing inputs (62).

Groundwater

The Indus plains have deep alluvial deposits, forming an extensive groundwater aquifer with potentially good supply. Before extensive systematic irrigation began, the groundwater table was well below the surface, with outflow balanced by natural recharge. Percolation to the aquifer was greatly increased when large-scale irrigation was introduced and recharge increased severalfold. The water table has risen to within about 3 meters of the surface in over half of the irrigated area and to within 1.5 meters or less in some areas, generating waterlogging and soil salinity problems (24, 799).

Groundwater use for irrigation, primarily from tubewells, was estimated at about 32 billion m^3 in 1975, with more than two-thirds of this coming from private tubewells. Groundwater supply was projected to increase to about 38 billion m^3 by 1980 and to about 43 billion m^3 by 1985 (62).

Pakistan's Mangla dam, part of the Indus Basin Development Scheme: Main embankment in top photo; spillway in bottom photo (World Bank photo by K. Muldoon).

It is difficult to estimate the ultimate water potential from groundwater sources in the absence of definitive hydrologic surveys. Also, the extent of surface water irrigation strongly influences groundwater availability. Available usable groundwater recharge would be more than 55 billion m^3 with full development of surface water resources and the canal system (24, 800).

Irrigation Methods and Cropping Patterns

Pakistan's irrigation canal system covers over 15 million hectares, although not all of this actually receives water. The total length of the canal system is about 38,000 miles. The system supplies 42 separate canal commands ranging from about 16,000 hectares to 1.2 million hectares (62).

Although groundwater use has increased sharply since the early sixties, surface water dominates as the source of irrigation water; canal system capacity is gradually increasing. In the midseventies, surface water accounted for almost three-fourths of total water availability at the farm gate in the kharif season and about 60 percent in the rabi season. Almost 10 million hectares are irrigated with canal water (62).

Construction of the canal system often ignored the need for adequate drainage systems. This has caused major waterlogging and salinity problems over large areas. About 11,000 public tubewells have been installed under the government's Salinity Control and Reclamation Projects (SCARP). They have a dual purpose: controlling waterlogging and soil salinity, as well as providing irrigation water. Farmers have installed over 150,000 tubewells which, although dug primarily to provide irrigation water, also contribute to controlling the water table (62).

Over three-fourths of the total groundwater used for irrigation is supplied by private tubewells and Persian wheels, the latter frequently powered by animals. Tubewells provide greater control over timing of irrigation deliveries, a factor often more important than the quantity of water (62).

Rapid growth of tubewells after 1960 can be explained by three factors: an active role by the government in promoting public tubewells for water development and control of salinity, coupled with government aid to the private sector in digging tubewells; easy and cheap availability of power, machinery, and skill for installing private tubewells; and demonstrated profitability of tubewell irrigation, due to the greater cropping intensity on tubewell irrigated farms and the rise in prices of agricultural products in the sixties. Rapid expansion of tubewells coincided with a significant decline in costs of installation, and operating costs fell as electricity became more available in rural areas. The government continues to encourage installation of private tubewells by heavily subsidizing them (8, 153).

About 10,000 private tubewells were installed annually during 1965-70, but this rate declined to only about 3,000 per year during 1970-75, with some recovery in more recent years. Installation of public tubewells also slowed during 1970-75, due to lack of finance. Tubewells supply water to an estimated 2 to 2.5 million hectares, with other wells and tanks supplying another 1 to 2 million hectares (62).

An estimated 80 to 90 percent of Pakistan's agricultural production comes from irrigated agriculture. Irrigated crops include rice, wheat, corn, sugarcane, beans, and cotton. Almost all rice and sugarcane production comes from irrigated land, about 90 percent of the wheat, and 95 percent of the cotton. Nonirrigated, or rainfed, areas lie largely in the north and northwest in regions where annual precipitation is 400 millimeters or more (62).

Only about 30 million hectares of Pakistan's total of 80 million can be cultivated. Only about two-thirds of the 30 million is actually cultivated (8, 153).

The canal system commands over 13 million hectares of culturable land, including some presently uncultivated areas. Almost 12 million hectares are irrigated each year, with some being double cropped. More than 60 percent of the irrigated area has water rights for year-round (perennial) supplies, while the remainder receives canal water only in the kharif season when river flows are more plentiful. Two-thirds of the irrigated area is in Punjab province, another 30 percent in Sind, and the remaining 3 percent in Baluchistan and Northwest Frontier Province (62).

There is some double cropping but nearly half of the cultivated area lies fallow during either the rabi or kharif season. Irrigated areas, including double cropping, in the kharif and rabi seasons are about 6 to 6.5 million hectares and slightly more than 7 million hectares, respectively. Cropping intensities for the rabi season are about 15 percent less than for the kharif season on perennial commands (those with year-round water rights) and about 25 percent less on nonperennial commands, due to increased evapotranspiration rates. Tubewells, however, tend to smooth out seasonal differences in cropping intensity (62).

Deep alluvial soils of the Indus plains, combined with the extensive irrigation system and favorable climate, provide tremendous potential for agricultural production. Yields have been relatively low despite this potential although substantial gains are now being made. Some underlying problems include: increasingly adverse soil conditions reflecting gradual spread of waterlogging and salinization, and farmers' uncertainty as to

whether they will receive water in a timely, predictable, adequate manner (35, 1; 62).

The sixties were generally good agricultural years in Pakistan; wheat and rice showed good increases in yields, especially during 1965-70. Yields tended to stabilize in the seventies with, for example, little increase in the use of high-yielding varieties of rice in the early seventies. The annual rate of increase in rice production in Pakistan during 1965-73 was almost 8 percent. Of this, 1.4 percentage points were attributed to an increase in irrigated area; another 1.7 percentage points were attributed to increased fertilizer use on the irrigated land, according to Herdt. The residual 4.8 percentage points included a contribution to yield from the improved average quality of land arising from a higher proportion of irrigated area (29, 4).

Waterlogging and Salinity Problems

Waterlogging and salinity have become major problems for Pakistan's agriculture, resulting from a serious imbalance between the capacity of the expanding irrigation system to bring water to the land and the ability to remove excess water and salt. Drainage facilities, either natural or constructed, are seriously lacking, with the result that yields on millions of hectares have been substantially reduced. Water tables have risen sharply in many areas. The Pakistan Government estimated that the water table is within about 3 meters of the surface on more than half of the irrigated area and within 1.5 meters in some regions (62; 24, 799).

Overwatering tends to produce waterlogging, adversely affecting yields in some areas. Salinity, brought about by underwatering and lack of drainage, keeps yields low in other areas.

Accumulation of harmful levels of salts in upper soil layers results from two factors: upward capillary movement of soil moisture which contains salts and the evaporation of this moisture near the soil surface, a particularly serious problem in areas where the water table has risen; and the common practice of underwatering or spreading the available irrigation water supplies over too large an area. This further aggravates the situation because the soil does not receive enough water to leach out accumulating salts (24, 796).

An estimated 2.5 to 3.5 million hectares may have severe salinity problems, with another 2.5 to 4.5 million hectares moderately affected. The provinces of Sind and Punjab are areas most damaged (62).

Technology for reducing waterlogging and salinity is well known but investments in appropriate projects have tended to lag.

Three partially overlapping solutions are: reduce amount of overwatering; teach farmers how to better manage irrigation water supplies; and provide an adequate drainage system. The government's Salinity Control and Reclamation Projects (SCARP) program, launched in 1959, is a major effort aimed at correcting some of the most serious waterlogging and salinity problems (62).

Water Management and Pricing

A major water management problem in Pakistan is inefficient irrigation water use. The previously assumed estimate of overall watercourse command efficiency of around 60 to 65 percent probably is too high (62).

Between 20 and 70 percent of the water available at the watercourse head is lost by the time it reaches the individual field diversion, according to a Colorado State University team. The magnitude of delivery system losses depends on the quality of maintenance of the watercourse, length of the watercourse, frequency of cleaning, and the total quantity of water available. Application efficiency is also extremely variable, not only by area but also by time of year. 13/ The average application efficiency in Pakistan is unlikely to exceed 65 percent to 75 percent, according to the Colorado work cited by Johnson, Early, and Lowdermilk. Based on a survey covering seven different agricultural climatic zones and 19 watercourses, the study estimated an average overall irrigation efficiency (product of the delivery efficiency times the application efficiency) of about 44 percent (35, 2).

Lowdermilk, Early, and Freeman cited 1975-76 Colorado State University data collected from a sample of 387 farmers located in 16 villages and 40 watercourses. The research sites were selected to represent major agro-climatic zones, but the authors noted that there was a disproportionately large sample of villages characterized by small farmer owner-operators. Farm conveyance efficiencies were low for all 40 watercourses, ranging from 35 to 67 percent. Field application efficiencies ranged from about 30 to almost 90 percent, with a mean and median of 50 and 60 percent, respectively. Overall weighted mean irrigation efficiency for the 40 sample commands was about 41 percent. This estimate, which the authors considered conservative, was much lower than the 60- to 65-percent range usually assumed. Much of the conveyance and field losses resulted from operational and management problems (41, vii,4,11,15).

13/ Application efficiency is the ratio of water stored in the root zone of a plant compared with the water applied in the field.

A 1976 World Bank study, based partly on the 1974 Colorado report, also judged the previously assumed 60- to 65-percent overall efficiency as too high. The Bank estimated a watercourse conveyance efficiency of about 75 percent and a field efficiency of about 65 percent, giving an overall efficiency of only about 50 percent (62).

A cause for inefficient water use may be very low water charges. Farmers place a high value on water during shortages. But, at other times, low water cost, along with uncertainty about timing of the next irrigation, means that farmers take whatever water they can, even if it exceeds requirements. Prices received by farmers for various agricultural products have increased at a much faster rate than have water rates per hectare. For example, the price received for wheat increased by 300 percent between 1955/56 and 1973/74 while the water rate increased by only 144 percent. Comparable figures for rice were 350 percent and 98 percent and for sugarcane, 198 percent and 166 percent (62).

Investment in Irrigation

There was a substantial drop in the share of budget allocations to agriculture, including irrigation and drainage development since 1960 (table 12). Water development expenditures accounted for more than a third of all development funds and other agriculture expenditures about 8 percent during the first 2 years of the 1970-75 period. Over the last 2 years of that period, water development expenditures fell to a fifth of the total while other agriculture expenditures rose to almost 12 percent (62).

Planned public sector allocations for water resource development and other agriculture during 1975-80 amounted to about 32 billion rupees (U.S. $3.2 billion), about 22 percent of all development expenditures, the same share achieved in 1977/78.

Table 12--Pakistan's share of total public sector outlays devoted to agriculture

Sector	1960-65	1965-70	1970-75	1975-80 (planned)
	Percent			
Water	43	37	24	12
Other agriculture	8	9	10	10
Subtotal	51	46	34	22
Nonagricultural sector	49	54	66	78

Source: (62).

Water resource development allocations accounted for about 17 billion rupees (U.S. $1.7 billion), about 12 percent of total planned development expenditures. This represented an increase in expenditures in real terms but a much lower share of the total than in previous periods. The SCARP program was planned to continue absorbing a very large share of the water development allocations, almost 40 percent (62).

Plans and Prospects

Most anticipated increases in food production by 1990 in Pakistan would come from more intensive use of existing cultivated land, although the other two approaches cited by IFPRI (see p. 5) will make some contributions. The IFPRI study projected only a 3-percent increase for Pakistan in the area equipped for irrigation, to a total of about 13 million hectares: A substantial increase in the cropping intensity index was projected, however. The index reaches 130 in 1990, giving a gross irrigated area of almost 17 million hectares. This would require a concerted effort in improving existing irrigated land and providing improved water management practices. The study projected that about 55 percent of the area benefiting from investment in new or improved irrigation would be allocated to food production (48, 48-9).

The IFPRI authors projected that increased investment in irrigation will cause food production to increase by 5 million tons by 1990. Ninety percent of this increase was projected to come from improvements in existing irrigation facilities, such as drainage and reclamation associated with salinity problems. These yield projections assumed improved irrigation management and increased fertilizer use at about recommended dosages. Improved yields also accounted for an additional 4-million-ton increase in production from area already under irrigation in 1975, giving a total increase in production from irrigated areas of an estimated 9 million tons (48, 86).

Expansion in rainfed area and accompanying yield increases over the entire rainfed area were projected to add another 1 million tons. Thus, the total increase in food production would be an estimated 10 million tons above the 1974-76 level of 13 million tons, bringing the projected 1990 food production level to about 23 million tons. If the goals outlined above could be achieved, with substantial contributions from improved irrigation and from increased inputs, then the production level attained in 1990 would about match the projected consumption under a low-income growth scenario, but would fall short under a high-income growth scenario (48, 26,86).

The total capital investment required for the projected expansion of irrigation for food production would be slightly over U.S. $2 billion, with almost three-fourths of this being

spent on irrigation improvements and only about a fourth on new irrigation (48, 60).

INDONESIA

Major future expansion of Indonesian irrigated areas is likely to occur on islands other than Java, with emphasis on small-scale projects. The irrigation systems should facilitate rice production in excess of consumption needs by 1990, according to a study by Nyberg and Prabowo. With further improvements in irrigation technology, areas could be shifted to alternative food crops during the 1990's.

Climate

Indonesia has a hot, rainy climate with average annual precipitation of more than 2,500 millimeters. Rain is typically tropical-frontal, convectional, and orographic and much of it comes with great intensity. Average annual rainfall varies widely--between 700 millimeters and 7,000 millimeters--but normally exceeds potential evapotranspiration which ranges from 1,200 to 1,400 millimeters per year (24, 459; 11, 1793).

Rainfall in Java ranges from more than 4,000 millimeters on the windward slopes of the mountains to less than 1,000 millimeters in the east. The eastern part of Java is the only part of Indonesia with a relatively distinct dry season, from June or July to October. Most of Kalimantan has heavy rainfall through the year. Totals exceed 2,500 millimeters in the middle and north, 2,000 to 2,500 millimeters in the southern and eastern lowlands, and 4,000 millimeters in the mountains (24, 459).

The west monsoon from November to May brings the heaviest rains. It originates as a northeast wind from the South China Sea and western Pacific where it picks up much moisture and then becomes a west wind after crossing the equator. The east monsoon, bringing little rain, occurs in June to October. It originates from Australia and becomes a southwest wind as it crosses the equator, linking with the main Asian monsoon (56, 21).

Surface Water

Average annual runoff in Indonesia is estimated at about 2,530 billion m^3, or an equivalent depth of about 1,250 millimeters. With an average annual rainfall of about 2,620 millimeters, the annual runoff coefficient is about 0.48. Numerous rivers and streams are located in all parts of Indonesia, with the biggest on the larger islands of Sumatra, Kalimantan, Java, and Irian. Some of the rivers may have a flow in excess of 2,000 m^3 per second during the rainy season, while in the dry season the flow is only a very small fraction of this amount. Some of the important rivers in Indonesia are the Brantas, Solo, Seraju, Tjitmauk, and Tjitarum in Java; the Asahan and Musi in Sumatra; and the Barito, Kapuas, Mahakam, Kajan, and Kahajan in Kalimantan (10, 391; 24, 460).

Most of the run-of-the-river flow has already been put to use, Framji and Mahajan stated. Since river flows are small in the dry season and much of the water is used in the mountains, irrigation schemes in the plains frequently are able to irrigate only 20 to 30 percent of the area equipped for irrigation. Further exploitation of surface water resources depends on storage of water during the rainy season. There would be enough water for whole-year irrigation if the abundant wet season flow could be stored. Suitable dam sites exist in many parts of the country (24, 460; 19, 280).

On the island of Java, for example, the Directorate-General of Water Resources Development (DGWRD) proposed a number of medium- to large-scale dams designed to increase the water supply to existing systems. The total storage capacity of these proposed dams was estimated at about 8.3 billion m^3 which, depending on type of crop, soil conditions, and demands for other uses, could probably irrigate an additional half million hectares per year. The problem in Java is that potential storage areas are frequently in irrigated, densely populated, and very fertile river valleys. Therefore, there are social, political, and economic factors to be considered in evaluating advantages and disadvantages of developing such storage facilities (62; 19, 280).

Groundwater

Groundwater use has been primarily for domestic water supply. There is inadequate data on the geological and hydrological characteristics of the groundwater resources, but a number of studies are investigating the technical and economic feasibility of groundwater development. The best groundwater bearing aquifers are lava streams, restricted to the vicinity of volcanoes and limestone areas. Yields of over 2,000 liters per second have been recorded. Most alluvial plains along rivers and coasts and near lake sites are considered to be good water bearing formations. Much of the Java groundwater is at least 100 meters below ground level (24, 460; 62).

Irrigation Methods and Cropping Patterns

Indonesia irrigated areas are usually classified according to the type and quality of the irrigation facilities provided. Three major classifications commonly used are "technical," "semitechnical," and "simple." In addition, "tidal/swamp" irrigation projects are often included although these are not strictly irrigation systems since they usually allow little control over water supply and mainly provide drainage (62).

Technical irrigation systems are large permanent works constructed and operated by a government agency. Their water supply is separate from the drainage system, and the volume of incoming water delivered can be measured at a number of points.

Indonesia's irrigation system is served by this diversion dam in West Java (International Development Assoc. photo by T. Sennett).

Semitechnical irrigation systems are generally constructed by government but operated by farmer organizations. They have fewer permanent structures than technical systems, have only one water measurement device, and the supply and drainage systems are not always separate.

Simple systems have no measurement devices, and conveyance systems for water supply and drainage generally are not separate. Many of the "village" systems are simple systems built and operated entirely by the local community.

The "Sederhana" program was initiated in 1975. These "simple" irrigation schemes, primarily designed for implementation by provincial public works organizations outside Java, are small, run-of-the-river projects, no larger than 2,000 hectares. They are relatively inexpensive (with costs ranging between U.S. $250 and $500 per hectare) and simple to design and construct. They aim to provide rapid and substantial increases in rice production, provide more earnings for the poor, rural population, encourage transmigration schemes, and, thus, contribute to regional development (62; 11, 1793).

About 80 percent of the conventional projects under construction or in the design stage in the second plan period (1974/75-1978/79) were less than 2,000 hectares. While these projects accounted for only 30 percent of the area involved, they were a significant part of the irrigation program. Almost 800 projects had been programmed through fiscal year 1978/79, with an original target area of more than a half million hectares. Less than half this target area had been completed by 1977/78 (62; 47, 24).

Tidal/swamp irrigation is a system using the tidal effect to irrigate and drain farmlands. There is little control over the water supply in the systems now in use, but more sophisticated systems are being designed to allow greater control. In basic tidal/swamp irrigation, canals are dug from the rivers inland or from river to river, and the land around these canals is drained during low tide and flooded during high tide. Use of this method can change swampy land to useful paddy fields in about 2 years. Land can be reclaimed up to about 5 kilometers on both sides of the canals. The reclamation procedure consists of: construction of a main canal which functions mainly as a drain connecting a tidal river with the swamp area; construction of simple access roads usually adjacent to canals; construction of a network of secondary canals to permit distribution of fresh water from the river by gravity at high tide and drainage into this same network during low tide; and clearing of vegetation, land leveling, settlement, and cultivation. In additional refinements of this system, dikes and gates are built to prevent

flooding and brackish water from entering the canals, forming a semipolder. A final stage is the polder system where drainage is done by pumping without depending on tides, and irrigation water is provided during the dry season by pumping from upstream water (62; 19, 280; 25, 116).

There are an estimated 35 million hectares of coastal swamp. Tidal/swamp irrigation may be a way of making some of this area productive, particularly in Sumatra and Kalimantan, but there are technical difficulties limiting the extent of the program. For example, some of the areas have potential acid sulfate soils which require very careful water management. And, in many regions, topographical conditions may make it difficult to maintain the desired water table levels. The saltwater intrusion problem may be difficult to solve in some locations. In addition, the remoteness and health hazards of some of the areas make them unattractive for settlement. Though tidal/swamp irrigation is only a small part of total water resource development for agriculture, it is important in the context of expanding rice production and in supporting the transmigration program (12, 57; 62).

The command or service areas of the Indonesian Department of Public Works total about 4.35 million hectares (table 13). About 44 percent of this is technically irrigated, 23 percent is semitechnically irrigated, about 25 percent has a simple irrigation system, and the remainder is tidal/swamp irrigation.

Table 13--Irrigation service areas of the Indonesian Department of Public Works, 1978

Region	Technical	Semi-technical	Simple	Subtotal	Tidal/ swamp	Total
	1,000 hectares					
Java	1,575	459	547	2,581	--	2,581
Bali	--	47	6	53	--	53
Sumatra	232	225	362	819	209	1,028
Kalimantan	5	25	35	65	130	195
Sulawesi	70	148	97	315	--	315
Nusatenggara	33	81	66	180	--	180
Total	1,915	985	1,114	4,013	339	1/ 4,352

-- = Negligible.
1/ In addition, there are at least another 1 million hectares under village control, over half of which are in Java and almost 30 percent in Sumatra (62).
Source: (47, table A.2).

Service areas exceed actually irrigated areas to the extent that a system has an inadequate water supply or needs rehabilitation or additional onfarm development. Java-Bali, with only about 7 percent of the country's land area, contains about 60 percent of the Public Works irrigation systems and has over 80 percent of the technically irrigated land. Technically irrigated land has both higher yields and higher cropping intensity. Sumatra contains almost a fourth of the Public Works irrigation systems and over 60 percent of the tidal/swamp irrigation. Kalimantan is the other major area with tidal/swamp irrigation.

A rough approximation of the condition of the Public Works service areas can be obtained from tables 13 and 14. Table 14 indicates the area of land with an assured water supply in the wet and dry seasons and therefore eligible for the government's subsidized credit (intensification) programs. 14/ In the wet season, almost 3 million hectares (table 14) of Public Works area had sufficiently good water control for intensified rice production, about three-fourths of the 4 million hectares in the service area (table 13). About 1 million hectares of the Public Works irrigation service area needed additional water supplies or some form of rehabilitation for full irrigation. In the dry season, only about 1.4 million hectares were suitable for the rice intensification programs, slightly less than half the eligible wet season area. Quality of irrigation facilities is a major factor affecting cropping intensity, so that as rehabilitation is completed the area planted to both wet and dry season crops should expand.

Table 14 also shows rainfed paddy land in wet and dry seasons. Rainfed land normally includes bunded fields which rely solely on rain for the water supply. But Nyberg and Prabowo noted that these fields often receive drainage water from other paddy fields (47, 5).

O. Djojoadinato, Director of Irrigation in the Indonesian Directorate-General of Water Resources Development, noted that the plains area of Indonesia, with a slope of less than 8 percent, comprises about 79 million hectares, but only the alluvial plains are well suited to irrigation (table 15).

Only about a fourth of the alluvial land and 5 percent of the total plains area were irrigated. Much less land is available in Java for further extension of irrigation than in the other islands, especially in Sumatra and Kalimantan (18, 25). Irrigation system developments during the first two 5-year plan

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14/ This does not necessarily mean that the credit programs are used, or that rice is even grown on the area.

Table 14--Indonesian land area with assured water supply suitable for intensified rice production programs, by type of irrigation (dry season 1978 and wet season 1978/79)

Region	Public works						Nonpublic works		Subtotal		Rainfed		Other		Total	
	Technical		Semitechnical		Simple											
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
	1,000 hectares															
Java	685	1,363	145	423	56	278	242	530	1,128	2,595	14	545	1	--	1,144	3,140
Bali	--	--	30	34	4	5	26	48	60	87	--	4	--	--	60	91
Sumatra	63	123	137	173	87	223	151	255	438	774	142	259	206	187	785	1,220
Kalimantan	1	3	9	14	6	27	13	19	29	63	71	189	168	306	268	558
Sulawesi	53	88	54	45	51	40	79	108	238	280	209	111	2	--	448	391
Nusatenggara	22	65	8	46	2	35	7	38	38	184	--	98	--	--	38	281
Total	824	1,641	383	735	206	608	518	998	1,931	3,983	435	1,205	377	494	2,743	5,681

-- = Negligible.

Source: (47, Tables A.4, A.5)

(Repelita) periods and targets for the current plan appear in table 16.

Operation and maintenance of primary and secondary irrigation systems have been the responsibility of the provincial public works service and beyond that point farmers' organizations have had responsibility. Neglect in operation and maintenance has necessitated large expenditures in rehabilitation (62).

Java and Bali accounted for about 60 percent of the harvested rice area and 65 percent of production in 1978 (table 17). Java

Table 15--Indonesian plains, alluvial plains, and irrigated areas, 1975

Region	Total plains	Alluvial plains	Irrigated
	Million hectares		
Java	3.0	2.0	2.7
Sumatra	27.6	2.4	.7
Kalimantan	24.5	4.3	.1
Sulawesi	3.2	.8	.3
Other provinces	20.6	7.3	.3
Total	79.0	16.8	1/ 4.1

1/ This total may exclude irrigation under village control.
Source: (18, 27).

Table 16--Indonesian irrigation development

Type of development	Repelita I (1969/70-1973/74)	Repelita II (1974/75-1978/79)	Total	Target for Repelita III (1979/80-1983/84
	1,000 hectares			
Rehabilitation	953	527	1,480	814
Expansion	191	273	464	766
Tidal/swamp development	179	272	451	535

Source: (47, 3).

Table 17--Indonesian harvested rice area, yield, and production of wetland paddy, 1978 1/

Region	Harvested area	Yield	Production
	1,000 hectares	Kilograms per hectare	1,000 metric tons
Java	4,467	3,404	15,206
Bali	159	3,526	560
Sumatra	1,515	3,013	4,564
Kalimantan	571	2,130	1,216
Sulawesi	695	2,909	2,022
Nusatenggara	244	2,848	695
Maluku	.5	2,138	1
Irian Jaya	.4	2,110	1
Total	7,653	3,171	24,266

1/ Data include both irrigated and rainfed paddy including tidal/swamp irrigation.
Source: (47, table A.7).

and Bali together with the provinces of North and West Sumatra, Lampung, South Kalimantan, and South Sulawesi had 80 percent of the area and 83 percent of production. These provinces are the primary rice producing areas of Indonesia and have the highest yields.

Wetland rice production increased 30 percent between 1971 and 1978. Production on Java increased by about a fourth while production elsewhere grew by more than a third (47, 6).

Rice cropping intensities have been increasing faster in regions other than Java and Bali, although the latter still lead the country. Based on a 1976 Indonesian Bureau of Census survey, Nyberg and Prabowo estimated that the overall rice cropping intensity for Java-Bali is 150 percent and is only 116 percent for the rest of Indonesia. The major rice producing province off Java--South Sulawesi--had an estimated rice cropping intensity of 128 percent. Technically irrigated land has the highest rice cropping intensity (47, 8).

Rice yields were lower on Java than on the other islands in the immediate post-World War II period. By 1976-78, however, yields on Java were almost a fifth higher, in part the result of rice intensification programs. The effect of water control on yields is quite significant. Indonesian experimental data suggest

yields potentially approaching 5 tons per hectare both on and off Java when the land is technically irrigated and 150 kilograms or more of urea are applied per hectare as part of an intensification program (47, 8,9).

Indonesia's irrigated land is used primarily for rice production. Other crops such as sugarcane, soybeans, and corn are also irrigated, mainly on Java, but data on irrigated areas of these crops are not available, although perhaps half of the 200,000 hectares of sugarcane are irrigated. In areas where irrigation systems are incapable of delivering adequate water supplies for rice production during the dry season, crops such as corn, pulses, and cassava are grown, using residual soil moisture and rainfall (62).

Water Management and Pricing

The greatest potential for improved water management is at the farm level, according to Nyberg and Prabowo. The farm-level water distribution system is operated by farmers without fixed control and measurement structures for field-level distribution of water. These authors stated that a major fault of the system is poor timing of water release to the paddy fields relative to the water requirements of the crop at various stages of growth. Irrigation water management and utilization in central Java is very inefficient at the farm level, suggested one study. It indicated that, in the absence of a water tax, farmers tend to use excessive amounts of water, and that irrigation water use was perhaps 50 percent greater than crop requirements (47, 12).

Farmers' associations on Bali, however, tend to be strong and have the power to enforce better water management. Fukuda described these "subak" as originating as a cross between a traditionally self-governing body and a Hindu religious festival. Because of detailed regulations and provisions for punishments in the system of water management, the "subak" are able to provide fair and even water distribution among farmers (25, 115).

Legally, the cost of water distribution and maintenance of the irrigation networks must be borne by those receiving direct benefits from the irrigation water. The cost of operation and maintenance of primary and secondary canals in government irrigation systems is financed mainly from provincial government budgets. Contributions to the cost of regional development are collected from landowners through the Iuran Pembanguanan Daerah (IPEDA) tax. This is basically a general land tax which includes charges for irrigated paddy land and is assessed on the basis of the quality and productivity of the land. The tax is levied at 5 percent of the net value of production. Construction of an irrigation system increases the net value of the land and thus the tax increases. Some of the proceeds from

Indonesian workers maintain a distribution irrigation canal in southeast Sumatra (FAO/World Food Programme photo by A. Moyse).

this tax are spent in the operation and maintenance of the irrigation systems, with supplemental subsidies from the central government (47, 16,17; 62).

There is no formal water charge other than this IPEDA tax levied on farmers for maintenance of primary and secondary canals. Operation and maintenance costs of tertiary canals, which are the responsibility of farmers' organizations, are paid in the form of money, labor, or in-kind (that is, formal and informal payments by farmers to those in the village responsible for the allocation and distribution of water) (62).

Even though Indonesia has no nominal water tax, farmers in an East Java project were already paying more for irrigation than what was being spent on operation and maintenance, according to Taylor in 1978. While farmers received economic benefits from irrigation, farm sizes were so small in the project area that annual agricultural incomes were also very small. Taylor concluded that these findings, plus the fact that the government, agro-industries, and the public also benefit substantially from irrigation, suggest caution in increasing the water charges to farmers (58, 111).

The best option is to use the IPEDA land tax as a means of collecting water charges from farmers benefiting from irrigation rehabilitation schemes, according to Booth. This would mean increasing the IPEDA assessment on rehabilitated areas and earmarking a substantial proportion of the proceeds to pay for operation and maintenance costs. She suggested that the other major alternative would be to levy a water charge in-kind through some form of voluntary wateruse organization (12, 60,61).

Investment in Irrigation

Substantial Indonesian resources were devoted to the irrigation subsector during the first two 5-year plan periods (table 18).

In addition to these Indonesian resources, foreign aid provided over 30 billion rupiah (U.S. $75 million) in Repelita I and about 150 billion rupiah (U.S. $360 million) in Repelita II. Total expenditures over the 10-year period thus were over U.S. $2 billion (840 million rupiah), including foreign assistance. Table 18 shows the substantial increase in budget allocations in Repelita II. Even taking into account the annual inflation rate, the real rate of growth was significant. The share of expenditures devoted to irrigation expansion in Repelita II increased, with a corresponding decline in the share of expenditures on rehabilitation (62).

Irrigation accounted for almost 10 percent of the development budget allocations in 1977/78 and increased to almost 12 percent

Table 18--Indonesian development budget allocations to irrigation

Type of development	Repelita I 1969/70-1973/74	Repelita II 1974/75-1978/79
	Billion rupiah 1/	
Irrigation rehabilitation	50.0	144.0
Irrigation expansion	25.0	195.7
River and flood control	6.3	196.7
Swamp/tidal development	33.1	2/
Total	114.4	3/ 546.6

1/ U.S. $1.00 = Rp 415 for all years, except U.S. $1.00 = Rp 385 for 1969/70-1970/71.
2/ Included in river and flood control expenditures.
3/ Includes a small amount for central government overhead.
Source: (62).

in 1978/79. 15/ When foreign aid and routine expenditures are included, irrigation has accounted for about 5 percent of the total Indonesian budget in recent years. If Indonesia is to achieve a growth rate in rice production comparable to the expected growth in demand, then the annual allocation of development budget funds to irrigation by the end of Repelita III (1979/80-1983/84) will need to be about 20 percent greater (in real terms) than in the late seventies, concluded a 1978 World Bank study (62).

Budgetary expenditures will depend on the type of projects chosen and the rate of increase planned for irrigation development. The World Bank study estimated that the total capital cost of all the future potential irrigation and water resource developments identified by the Indonesian government probably would be $14 billion at 1978 prices. But, lack of solid information on soil suitability and economic feasibility makes it unclear whether all the area identified as irrigable really is (62; 47, 42).

Cost of rehabilitating conventional run-of-the-river gravity systems, including the cost of tertiary development, ranges between U.S. $1,000 and U.S. $2,000 per hectare (mid-1978 prices). Development costs for new gravity systems, including

15/ Agriculture and irrigation together accounted for about 19 percent of the total development budget (62).

storage facilities, vary widely but a range of U.S. $2,500 to U.S. $3,500 per hectare has been estimated (62).

Two highly publicized, new development programs are the Sederhana and the tidal/swamp reclamation programs. The Sederhana program, initiated in 1975, focuses on small-scale (fewer than 2,000 hectares) projects with a potential for quick returns. These are generally low-cost projects, ranging between U.S. $200 and U.S. $500 per hectare. Costs of tidal land development, on the other hand, have been on the order of U.S. $1,000 to U.S. $1,500 per hectare for drainage, clearing, and land development. If transmigration is involved, there are additional costs of about U.S. $800 per hectare to provide basic facilities for the transmigrants (62).

Plans and Prospects

Irrigation developments laid out in the third 5-Year plan (1979/80-1983/84) will not be completed to full yield potential until 1990, according to Nyberg and Prabowo. They judged that inflation will have eroded the very substantial budget increase allocated to irrigation. In real terms, new projects will be more costly on a per hectare basis since the easier projects have already been completed or initiated. Their projected inventory of irrigation systems by 1990 appears in table 19 (47, 35).

Table 19--Indonesian projected irrigation, 1990

Irrigation type 1/	Region: Java-Bali	Sumatra	Kalimantan	Sulawesi	Other provinces	Total	Percentage of total
	1,000 hectares						Percent
Technical	1,874	594	44	218	73	2,803	40
Semi-technical	518	285	39	172	94	1,108	16
Sederhana (simple)	563	407	45	115	75	1,205	17
Rainfed	471	199	168	93	87	1,018	15
Tidal/swamp	--	558	316	--	--	874	12
Total	3,426	2,043	612	598	329	7,008	100
	Percent						
Percentage of total	49	29	9	9	5	100	--

1/ See p. 44 for definitions.
-- = Negligible
Source: (47, 36).

Much rehabilitation of existing irrigation systems has been completed or is underway. Therefore, future irrigation development will likely concentrate somewhat more on construction of new gravity systems and tidal/swamp development outside Java. Also, groundwater development may become more important in the longer run (62).

Nyberg and Prabowo made several assumptions concerning use of inputs in deriving projected rice yields for 1990. For example, they assumed use of 200 to 250 kilograms of urea per hectare on Java-Bali under the BIMAS/INMAS programs (the government's intensified rice production programs involving new technology) and 150 to 200 kilograms per hectare for nonintensified rice production. On the other islands, use of 150 to 200 kilograms was assumed under BIMAS/INMAS programs and only 100 to 150 kilograms for nonintensified production. They also assumed some increase in the proportion of production grown under intensified programs. Table 20 projects rice yields for 1990, based on these assumptions (47, 37).

The estimate of almost 35 million tons of paddy production by 1990--based on cropping intensities displayed in table 21--implies an average annual increase of about 3.3 percent from the 1978 level, according to Nyberg and Prabowo (table 22). An additional 1 million tons of dryland rice can be expected (47, 38).

Development of Indonesia's irrigation potential could double the service area of the Public Works system now in existence or under construction, according to Nyberg and Prabowo (table 23).

Table 20--Indonesian projected rice yields, 1990

Irrigation type 1/	Region: Java-Bali	Region: Other islands
	Kilograms per hectare	
Technical	3,701	3,400
Semitechnical	3,691	3,510
Sederhana (simple)	3,551	3,276
Rainfed	2,950	3,162
Tidal/swamp	--	2,975

1/ See p. 44 for definitions.
-- = Negligible.
Source: (47, 37)

Table 21--Indonesian projected rice cropping intensities, 1990

Irrigation type 1/	Region				
	Java-Bali	Sumatra	Kalimantan	Sulawesi	Eastern Indonesia
	Percent				
Technical	170	147	178	169	155
Semitechnical	153	161	120	154	130
Sederhana (simple)	158	135	106	138	114
Rainfed	130	103	101	102	100
Tidal/swamp	100	100	100	100	100

1/ See p. 44 for definitions.
Source: (47, 37).

Future irrigation development will be in projects involving new irrigation areas or tidal/swamp land development. However, the authors pointed out that:

> "...this listing is very tentative and is acknowledged to overstate the potentially irrigable land. The data are approximations of land that could theoretically be irrigated from an engineering perspective. There is inadequate information available to determine whether the soils are appropriate for irrigation or whether irrigation would be economically feasible" (47, 41,42).

Irrigated area will expand at the rate of about 100,000 hectares per year between 1990 and 2000, Nyberg and Prabowo projected. The assumed increases included 800,000 hectares of conventional, technical irrigation (500,000 hectares on Sumatra and 100,000 hectares each on Java-Bali, Kalimantan, and Sulawesi). In addition, 100,000 hectares of additional tidal/swamp irrigation were projected in both Sumatra and Kalimantan. Most increases would occur on islands other than Java and Bali, especially Sumatra (47, 42).

Three alternative yield increases were selected for fully irrigated (nonrainfed) land in projecting yields to 2000, 1.00, 0.75, and 0.50 tons per hectare above the projected 1990 level. The middle alternative was assumed to be most probable, in which case Java-Bali yields in 2000 would approach current yields in Taiwan. Rainfed rice yields were assumed to increase to about 3.25 tons per hectare for all islands, and tidal/swamp rice yields were assumed to be 3.5 tons per hectare (47, 42).

Table 22--Indonesian projected rice production, 1990

Irrigation type 1/	Region					
	Java-Bali	Sumatra	Kalimantan	Sulawesi	Eastern Indonesia	Total
	1,000 tons					
Technical	11,791	2,967	265	1,250	385	16,658
Semi-technical	2,924	1,610	165	927	428	6,054
Sederhana (simple)	3,158	1,801	156	520	281	5,916
Rainfed	1,805	648	537	301	274	3,565
Tidal/swamp	--	1,660	938	--	--	2,598
Total	19,678	8,686	2,061	2,998	1,368	34,791

-- = Negligible
1/ See p. 44 for definitions.
Source: (47, 38).

Cropping intensities are likely to increase as new, shorter maturity rice varieties become available. Three alternative levels of increase were chosen, with the middle one deemed most probable: 40, 30, and 20 percentage points over the projected 1990 intensity values for fully irrigated paddy. The implied rice cropping intensity on irrigated land is about 185 percent for Java-Bali and almost 150 percent for the other islands. These intensities are low compared with the multiple cropping index of 225 percent for paddy land in Taiwan. The authors judged they should be attainable, given the expected more rapidly maturing varieties, better water control, and generally improved technology (47, 43).

Production of paddy in the year 2000 was projected to be about 55 million tons, based on the assumed increases in area and the most probable increases in yields and cropping intensities. The Nyberg and Prabowo projections for 1990 and 2000 were based on assumed incremental changes. While there is little solid information to substantiate the changes, they are within levels of technology and rates of change experienced in other countries. The entire 8 million hectares projected by 2000 probably would not be entirely planted to rice because the projected output of 55 million tons of paddy would be in excess of the country's needs. Part of the irrigated area might be devoted to alternative food crops during the 1990's (47, 43,47).

An Indonesian farmer transfers water to his paddy field from an irrigation channel (FAO photo by F. Botts).

Table 23--Indonesian potential irrigation development

Region	Conventional gravity irrigation: New areas	Conventional gravity irrigation: Rehabilitation	Conventional gravity irrigation: Subtotal	Tidal	Swamp	Total
	1,000 hectares					
Java-Bali	156	46	202	--	2	204
Sumatra	2,527	84	2,610	307	345	3,262
Kalimantan	684	24	708	254	365	1,327
Sulawesi	359	42	401	--	2	403
Total	3,726	196	3,921	561	714	5,196

-- = Negligible.
Source: (47, table A.18)

Indonesia should be able to manage the new development of 100,000 hectares per year of gravity irrigation systems, some 20,000 to 60,000 hectares of rehabilitation, and about 50,000 hectares of swamp and tidal development, according to a World Bank study. At this rate, 30 years or more would be required to complete projects in areas presently identified by the Indonesian Government as having irrigation potential. Annual cost of this development would be about U.S. $375 million in 1978 prices. 16/ New irrigation development at this rate would permit a rate of growth of Indonesian rice production of 1.5 to 2.0 percent annually (assuming zero growth rate without the new projects) to about 4 percent (assuming 3-percent growth rate without the projects), according to the study (62).

THAILAND

Expansion of irrigation has been an important factor in increasing rice production in Thailand. About 60 percent of the Thai public investment in agriculture has been for irrigation development.

Climate

Thailand's climate is subtropical to tropical humid. Rain is abundant with an annual average of 1,400 to 1,500 millimeters. But, there are sharp regional variations with 1,200 to 1,300 millimeters in the north and northeast regions, 1,300 to 1,400

16/ An additional U.S. $135 million for river and flood control and U.S. $125 million overhead are anticipated, giving an annual budgetary outlay of about U.S. $635 million, compared with the expenditure of about U.S. $520 million during 1978/79.

millimeters in the central region, and 1,900-2,600 millimeters in the south (24, 1066).

The climate is governed by the monsoons, with a wet and a dry season except in the south. The wet season, dominated by the southwest monsoon, occurs in May-October and brings about 85 percent of the annual rainfall in the central, north, and northeast regions. There is considerable variation in this wet season rainfall, and several weeks of drought frequently occur at the end of June and the beginning of July. The distribution and amounts are usually the least reliable in the northeast. Supplemental wet season irrigation is useful in all regions to carry crops over dry periods and thus stabilize yields (3, 51-2).

The southern peninsula has much more rain than does the rest of the country as well as a somewhat different rainfall pattern. The northeast monsoon, beginning in late October or November and continuing to mid-March, is more effective in the south. Hence rainfall is more constant over the year with less difference in rainfall amounts from month to month. Precipitation amounts to 2,000 to 4,000 millimeters on the east coast and 3,500 to 4,000 millimeters on the west coast where it rains all months (3, 51-2).

Surface Water

Thailand has abundant water resources, but their potential and regional distribution are difficult to estimate precisely in the absence of definitive hydrogeological surveys. For example, a 1975 UN conference paper on river basin development gave the volume of the average annual runoff as 200 billion m^3, about the same level as the 220 billion m^3 quoted by Framji and Mahajan. However, a 1977 UN water conference paper gave the average annual runoff as only 110 billion m^3, about half the other estimates. This source estimated 30 billion m^3 of water withdrawal for irrigation in 1975, presumably primarily surface water (9, 180; 24, 1068; 10, 391).

The principal rivers in northern Thailand are the Ping, Wang, Nan, and Yom. The Mekong in the northeast forms the boundary between Thailand and Laos and the Mun River is a tributary, which has the Chee as its tributary. Important rivers in the central plain are the Chao Phya, Pasak, Mae Klong, and the Petch. Most southern region land and water resources are on the east coast, such as the Pattani basin. The northeast has limited water resources and suffers acute water shortages in the dry season in spite of its relatively high average annual rainfall and fairly numerous tributaries. Soil conditions are not suitable for retaining water and existing basins are small. Also, cutting of forests in the practice of shifting cultivation has aggravated the water problem. Even full control of the region's rivers might irrigate less than 10 percent of the 3.5 million hectares of paddy land (24, 1068; 62).

The Chao Phya basin is the largest and most important in terms of land and water resource development. Second to the Chao Phya in size and development potential is the Mae Klong basin in the western part of the central region (62).

There are large seasonal variations in the flow of the rivers because of the monsoon. River flows drop sharply as the southwest monsoon ends in October and continue to decline until the beginning of the wet season in May. Without storage, irrigation for a single wet season crop is possible only near large rivers with a reasonably dependable wet season flow. Year-round irrigation for intensive double cropping depends on storage dams to conserve wet season runoff. Storage facilities approached 30 billion m^3 by the midseventies (62; 9, 181).

Groundwater

Groundwater development has been minor in comparison with surface water utilization. Groundwater potential for Thailand is small compared with surface water, according to preliminary hydrogeological data. Prospects, however, are good in the central plains, especially in the Chao Phya delta where groundwater has potential for dry season irrigation and industrial uses. Parts of the Yom basin and some southern areas have some potential (62; 24, 1068). Annual dependable water supply potential from groundwater in Thailand may be 30 billion m^3 (10, 392).

Irrigation Methods and Cropping Patterns

Thailand's 514,000 square kilometers of land include about 20 million cultivated hectares, of which about 14 million are cropped annually. The central plain, the rice bowl of Thailand, is a level, well-watered alluvial plain sometimes likened to a large lake during the rainy season. Land is used mainly for paddy. The mountainous northern region is covered with forests, but various crops are grown on the flood plains in the river valleys, with irrigated rice being a dominant crop. Potential for irrigation and intensive cropping in the north is largely restricted to the lowlands, which represent only about 10 percent of the total land area. Therefore, there is considerable pressure on this land and where dry season water is available, most of it is double cropped (62; 24, 1066).

The northeast, a high plateau sloping toward the Mekong River on the Thailand-Laos border, includes about a third of the total land area of Thailand but its soils have low waterholding capacity and low fertility. Rainfed rice is grown in the depressions and lower slopes of the low rolling hills. About half of the country's paddy land is in the northeast. Upland crops are grown, with kenaf and cassava being major crops on the higher soils (62).

The southern region, occupying the peninsular section, has a high annual rainfall with rice and plantations of rubber trees

Thai farmers pump water from a stream to irrigate their fields (FAO photo by F. Botts).

and coconuts grown in limited areas. Land suitable for field crops tends to be limited to the foothills, valleys of the numerous rivers flowing east to the Gulf of Thailand, small areas of flat to rolling land on the west coast, and larger coastal plains on the east coast (24, 1066; 62).

Irrigated area in Thailand has grown from 1.25 million hectares in 1956, 1.87 million in 1966, 2.45 million in 1976, and 2.72 million in 1978, according to Thailand's Royal Irrigation Department (RID). There is uncertainty whether these figures refer to total irrigated area (wet and dry season combined) or wet season only, although a total is implied (59, 1192).

Irrigation systems in 1977 provided at least some degree of water control for about 1.8 million hectares in the wet season and approximately 0.5 million hectares in the dry season, out of an annual crop area of about 14 million hectares, according to another source (table 24). Almost all wet season irrigation is devoted to rice. Lack of reservoirs for storing monsoon season floodwaters and low stream flows in the dry season severely limit irrigation in the dry season, although soils and climate are suitable for year-round crop growth. Potential for dry season rice irrigation from existing dams and those under construction was estimated at about 1 million hectares (62).

Rice is by far the most important crop in the wet season in rainfed and irrigated areas. About 7.7 million hectares are harvested annually, almost half of which is in the northeast, practically all rainfed. Another 40 percent is in the central region (62).

Table 24--Thailand's distribution of irrigated areas

Region	Irrigated area			
	Wet season	Dry season		Total
		Rice	Other crops	
	1,000 hectares			
North	420	45	50	515
Central	1,240	320	55	1,615
Northeast	50	10	10	70
South	90	5	5	100
Total irrigated area	1/ 1,800	380	120	1/ 2,300

1/ There are also 5.9 million hectares of rainfed and flood dependent rice in the wet season. Source: (62).

Rice is also the main dry season crop in irrigated areas (see table 24). The dry season rice area increased from 40,000 hectares in 1970 to 380,000 hectares in 1976 in response to favorable rice prices and improved water supply in the central region, where most dry season cultivation has taken place (62).

Most irrigable areas are in the floodplains of major rivers. Until the sixties, irrigation development was concentrated in the Chao Phya basin covering large areas in the north and central regions. Nearly 1.3 million hectares in this basin have wet season irrigation, and about 450,000 hectares are irrigated in the dry season. There is some opportunity for increasing dry season irrigation supplies, although most principal reservoir sites have already been developed. But, improved efficiency in water use would permit some increase in dry season irrigation. Wet season irrigation is available for about a fourth of the total crop area in the central region and for about 8 percent of the northern region, but is of much less importance in the rest of the country. Irrigation in the south tends to be concentrated on the east coast which has most of the region's 600,000 hectares of rice land. The low dry season flow of the rivers limits cropping to about 10,000 hectares, with half of this being paddy land (62).

The central region dominates irrigated paddy production: almost two-thirds of the wet season paddy production and more than 80 percent of the dry season production (table 25).

Yields of rice and most other major crops stagnated through the sixties and early seventies. There were minor increases in yields in all regions in the sixties except the south, as rice area expanded. Yields in the central plains increased after 1970 with an expansion in dry season cropping and use of new high-yielding varieties. Yields continued to stagnate in the south, and began to decline in the north and northeast. Expansion of rice cultivation into upland areas accounted for part of this decline, since average yields on upland are somewhat lower than for rainfed rice grown in lower areas. The decline was also partly due to declining soil fertility in the absence of significant fertilization (62).

Without irrigation, paddy rice yields averaged about 1.4 tons per hectare in the northeast (where rainfall is least reliable), 1.8 tons per hectare in the central and southern regions, and 2.2 tons in the north. Yields of over 4 tons per hectare can be attained with good water management and appropriate inputs and cultivation techniques. Ability to grow a second crop is the greatest benefit in areas where water is available for year-round irrigation. Dry season irrigated paddy also has a potential yield advantage of about 0.8 tons per hectare over the

wet season irrigated crop, largely because of better water control and higher solar radiation levels during maturation (62).

Area under upland crops, especially cassava, corn, and sugarcane, has grown rapidly and now exceeds 3 million hectares. Most expansion has occurred in the northeast and central regions. Production of upland crops is limited in the wet season because of heavy rainfall and surface drainage problems as well as traditional reliance on rice as the wet season crop. Soil quality and water control are dominant factors determining the potential for upland crops in the dry season. Probably no more than a fourth of the irrigated areas in the central region is suitable for dry season upland crops because of soil and drainage limitations (about 40 percent in the north and northeast) (62).

Irrigated upland crop yields have not been much higher than rainfed yields, so the main benefit of irrigation has been the ability to grow a second crop. However, given good water management and appropriate inputs, there is a substantial potential yield advantage. Tobacco, soybeans, vegetables, groundnuts, and mung beans are crops well suited for irrigated uplands in the north (groundnuts, vegetables, and mung beans in the northeast) (62).

Table 25--Thailand's paddy production, 1976

Region	Wet season	Dry season	Annual total
		1,000 tons	
North	1,170	160	1,330
Central	2,870	900	3,770
Northeast	130	15	145
South	230	15	245
Subtotal, irrigated	4,400	1,090	5,490
Rainfed and flood dependent rice	9,400	--	9,400
Total rice production	--	--	14,890

-- = Not applicable.
Source: (62).

Investment in Irrigation

Thailand's agricultural sector has been one of the most dynamic in Asia, contributing about 30 percent of the country's gross domestic product. The public sector's contribution to agricultural development has been mainly in providing physical infrastructure, especially roads and irrigation facilities, and crop research, with particular emphasis on rice breeding (62).

Public investment in agriculture has fluctuated between 7 and 10 percent of total government expenditures. Nearly 60 percent of the public investment in agriculture has been for irrigation development. Expansion of irrigation facilities has been a major factor in maintaining Thailand's comparative advantage in rice production. Road construction has provided access to new lands and has been the main stimulus for diversification into upland crops (62).

The budget for the irrigation development program of the Royal Irrigation Department (RID) in the fourth 5-year plan (1976-81) was set at about $1.4 billion (1976 prices) (table 26). The fiscal 1980 RID budget was about 5.3 billion baht (about U.S. $261 million), about a 20-percent increase over the previous year compared with an 18-percent increase in the overall budget (59, 1191).

Plans and Prospects

Much of the recent growth in agricultural production in Thailand has resulted from diversification into upland crops by bringing additional land into cultivation rather than from crop substitution or higher yields. Much of the potential for expanding cultivable area, however, has been exploited; further growth must

Table 26--Thailand's proposed budget for irrigation development, 1976-81

Item	Amount
	Million U.S. dollars 1/
Continuation of large project construction	350
Small project construction	130
Irrigation development and improvement	90
Roads and inland waterways	150
Large new projects	210
Operation and maintenance	150
Administration	320
Total	1,400

1/ U.S. $1.00 = 20.3 baht.
Source: (62).

depend increasingly on more intensive use of existing farmlands and on higher yields. The Mae Klong basin of the central region offers by far the greatest opportunity for increased production of any of Thailand's river basins, with its potential for considerable expansion of year-round irrigation. There is little opportunity for increasing dry season flow for irrigation in the important Chao Phya basin because of the absence of sites for large storage reservoirs. Improved efficiency of water use in both the wet and dry seasons, however, would permit some increase in dry season irrigation. Also, there is considerable potential for increasing paddy yields in the wet season (62).

The World Bank in 1976 estimated the increase in paddy production required to meet growing domestic demand and to maintain Thailand's share of the world market. Production would have to increase from 15.1 million tons of paddy in 1976 to 22.7 million tons in 1990. Assuming a yield increase of 20 percent in rainfed paddy areas, irrigated paddy production would have to more than double from 5.5 million tons to 12 million tons. A suggested program to help achieve this goal involved the improvement of about 710,000 hectares of the existing irrigation system, extension of existing systems by 290,000 hectares, and 315,000 hectares in new irrigation projects (62).

The proposed irrigation development strategy would permit a 60-percent increase in the total irrigated area by 1990 and a 40-percent increase in average yields of rice on irrigated land, reaching 3.5 tons per hectare by 1990. Most of the expansion in irrigated area is projected to take place in the central region, but important new projects are also planned for the lower north and the south. The northeast on the Mekong River also has potential for development (62).

Some increase in the area of upland crops such as corn, cassava, kenaf, and legumes can be achieved. A combination of increasing intensity of land use on present holdings, especially in the northeast, together with some expansion into forest and scrub areas, particularly in the south, is projected to permit an annual rate of growth in the planted area of somewhat over 2 percent from 1975 to 1990 (62).

An increase in rice yields is expected, partly as a result of the expanded irrigation program and partly due to use of high-yielding varieties and improved cultivation techniques. Higher yields are also expected for upland crops (table 27). These yield levels are modest when compared to present yield levels in some other East and Southeast Asian countries.

Combining these yield projections with the anticipated increases in area gives the estimated annual growth rates in the production of the various crops in comparison with historical growth rates (table 28).

Table 27--Thailand's yields of selected crops

Crop	1973-75 average	1990 (projected): Historical trends	1990 (projected): Proposed program
	Tons per hectare		
Rice (central region)	1.9	2.2	2.9
Rice (other regions)	1.6	1.4	1.9
Corn	1.7	1.5	2.1
Cassava	15.3	13.7	17.1
Kenaf	1.2	1.1	1.3
Sugar	47.0	47.0	47.0
Rubber	.4	1.2	1.2

Source: (62).

Table 28--Thailand's projected percentage increases in crop production, 1976-90

Crop	Annual growth rate of production: Historical trend	Annual growth rate of production: Proposed program
	Percent	
Rice (central region)	1.9	3.7
Rice (other regions)	.3	2.0
Corn	.5	5.6
Cassava	.4	6.1
Kenaf	- .1	2.7
Sugar	0	0
Rubber	8.4	8.8
Other crops	3.8	5.5
Agriculture	3.2	4.5

Source: (62).

BANGLADESH

Irrigation, according to Bangladesh's current plan document, will be a main "investment to bring about a radical change in agricultural practices and productivity." About 1.5 million hectares of the nation's 8.4 million hectares of cropped land are irrigated. The government plans to double irrigated area by 1985.

Climate

Bangladesh is in a typical monsoon region: warm and humid in summer and mild and relatively dry in winter. Average annual precipitation in Bangladesh is about 2,000 millimeters, ranging from 1,300 millimeters in the center and west to more than 5,000 millimeters in the northeast. Heavy rainfall comes from the southwest monsoon and frequent cyclones from the Bay of Bengal. There are three distinct seasons: summer (Mar.-May), monsoon (June-Oct.), and winter (Nov.-Feb.). Over 80 percent of the annual average rainfall occurs during the monsoon season when storms usually last several days and bring periods of steady rain. The 15-percent of rain coming in the summer arrives in high intensity, short duration showers. Little precipitation--normally less than 100 millimeters--occurs in the winter (10, 391; 24, 793).

Maximum evaporation occurs during March-May, with the highest usually in April. The mean monthly evaporation varies from about 50 millimeters in the winter to more than 180 millimeters in the summer. The mean annual evaporation ranges from about 1,000 millimeters to almost 1,400 millimeters. The rate of evaporation is generally lower in the eastern part of the country than in the western and northwestern regions (24, 794).

Surface Water

The greater part of Bangladesh lies within the delta of the combined Ganges-Brahmaputra-Meghna Rivers system. The drainage areas of these three rivers lie in five countries: India, Nepal, Bhutan, the Tibet region of the People's Republic of China, and Bangladesh. Their total drainage area lies in one of the heaviest rainfall areas of the world and covers about 1.55 million square kilometers, of which only about 8 percent lies in Bangladesh. Comparatively small rivers such as the Karnafuli, Sangu, and Matamuhuri drain the hilly regions in the southeast part of the country. All Bangladesh rivers are tidal near the sea (33, 173).

About 1,234 billion m^3 of water pour into Bangladesh from the three major rivers in an average year. To this surface inflow is added another 123 billion m^3 of rainfall runoff within Bangladesh. Most of this flow is concentrated in the June-September period. During this monsoon season, the combined discharge of the rivers totals more than 141,000 m^3 per second (5 million cubic feet per second), but this flow dwindles to only 5 percent of this level during the dry season (10, 391; 6, XII-78).

More water enters Bangladesh than can ever be used effectively. A UN report on river basin development estimated evaporation losses at about 160 billion m^3 with another 80 to 85 billion m^3 used by the current crop area of almost 9 million hectares. This gives a total consumption of about 245 billion m^3 or less than a fifth of the total annual supply. This overall picture, however, obscures the highly seasonal nature of the flow and the resulting water shortages which occur during the winter (1, 191).

The highly seasonal flow of water is a major problem for the development of water resources. About 84 percent of the rainfall in the Ganges plain occurs from June to September and 80 percent of the river's annual flow takes place from July to October. The high flow begins a little earlier on the Brahmaputra but two-thirds of its annual flow occurs in June to September. This problem of highly seasonal flow is compounded by the fact that the terrain is very flat so that there are relatively few sites suitable for construction of large storage reservoirs. More than half of the country has an elevation of less than 8 meters above sea level. This combination of flat terrain and highly seasonal river flow also causes severe flooding problems during the monsoon season (1, 187,191).

Large amounts of water are required during the nonmonsoon season for irrigation of crops and for control of saltwater intrusion. Maximum withdrawal of water for irrigation occurs during March and April when evaporation is at maximum. Perhaps 60 percent of dry season flow may be used for irrigation without adverse effects on navigation and other rural uses of surface water. Part of the water diverted for irrigation returns to the rivers as surface runoff or regenerated groundwater (1, 190).

Groundwater

Availability of groundwater depends on three major factors: proximity of the water table to the ground surface; amount of annual recharge in the basin; and quality of the water. Groundwater is available in large areas of the country, either in a shallow aquifer about 10 meters below the ground surface or else in a highly productive aquifer lying at a depth of about 100 meters. Most groundwater development has occurred in the northwest, which is the driest region. Depth of a suitable aquifer for installation of tubewells is, in general, less in the north and west than in the central, eastern, and southern regions (6, XII-78; 22, 103; 1, 189).

The "... vast potential for groundwater development has remained largely untapped, with the current installed capacity being less than 5 percent of the potential," according to a 1979 World Bank study which stated that "the scope for additional irrigation is enormous. Irrigation water supplies--mainly from

groundwater--are adequate for well over 10 million acres, compared to some 3 million acres currently under irrigation" (62).

The Bangladesh Water Development Board, assisted by the UNDP, is conducting a groundwater survey, expected to be completed by 1982. This survey should provide more definitive information on the potential use of groundwater for irrigation and for other purposes (6, XII-78).

Irrigation Methods and Cropping Patterns

Major constraints on agricultural growth in Bangladesh include the scarcity of cultivable land, limited potential on part of the land under cultivation, and climatic hazards such as droughts and floods with the resulting need for irrigation during the dry season and for drainage and flood control during the monsoon. The second 5-year plan (1980-85) document recognized these problems and stated that "water resources development, particularly irrigation, will be the main instrument to bring about a radical change in agricultural practices and productivity" (62; 6, XII-79).

Total area of Bangladesh is 14.28 million hectares. Cultivable area is about 9.4 million hectares, including cultivable waste and current fallow. Net cropped area in 1977/78 was 8.4 million hectares. About 4.7 million hectares were single cropped, 3.0 million hectares double cropped, and 0.6 million hectares triple cropped. This gives a total cropped area of 12.6 million hectares or a cropping intensity index of about 150 percent. The cropping intensity is highest in the northcentral and northwest areas, which have considerable irrigation, primarily from deep tubewells. Cropping intensity is lowest in the southwest, which has limited irrigation and is subject to tidal action, especially during the wet season (4, 38-9; 62).

Rice accounts for about 80 percent of the cropped area; cropping patterns center around rice. The three main paddy crops are: aus, or early rainy season varieties sown in March-April and harvested in July-August; aman, or monsoon season varieties sown in March-April or June-July and harvested in November-December; and boro, or dry season varieties grown under irrigation. Both aus and aman varieties may be grown from broadcast seed or transplanted. The transplanted crop tends to yield higher (62).

The common cropping pattern on relatively high land is aus rice or jute followed by transplanted aman rice in the monsoon season. Transplanted aman followed by pulses and oilseeds is also a common pattern in some higher land areas. The more common cropping pattern on intermediate land is aus or jute or transplanted aman, followed by pulses and oilseeds; an alternative is aus or jute followed by wheat, vegetables, or

Table 29--Bangladesh's area irrigated for selected crops, 1977/78

Crop	Area irrigated
	1,000 hectares
Rice	1,188
Aus	85
Aman	84
Boro	1,018
Wheat	94
Potatoes	62
Vegetables	42
Other crops	71
Total	1,457

Source: (4, 45).

coarse grains. Broadcast aman or mixed aus and broadcast aman are grown in low-lying areas. A single transplanted aman crop is grown in saline coastal areas or, in more favorable areas, transplanted aman is followed by oilseeds (6, XII-11).

Aman rice accounted for about 57 percent of the total rice area in 1977/78; aus rice, 32 percent; and boro rice, the remaining 11 percent (4, 47).

The irrigated area in Bangladesh is about 1.5 million hectares, substantially less than the designed capacity of the irrigation system (table 29). The second 5-year plan document gave the following as some of the major factors responsible for underutilization of capacity: improper location of the pumps and wells, operation of equipment at much less than the optimum number of hours per day, internal conflicts among the members of irrigation groups, seepage losses, and irregular availability of supplies and services. The designed capacity of the equipment installed by June 1978 was about 1.77 million hectares, but area irrigated at that time was only 1.16 million hectares, only about two-thirds of capacity (6, XII-40a,86,87).

The Bangladesh Water Development Board (BWDB) and the Bangladesh Agricultural Development Corporation (BADC) are the two major public sector agencies responsible for development of the country's water resources. One of the main functions of BADC is the supply of irrigation water through low-lift pumps and shallow and deep tubewells. 17/ These are usually small-scale

17/ The pumps are usually portable, diesel engines used to irrigate low-lying lands during the dry season with surface water from rivers and streams.

irrigation projects. The BWDB supplies irrigation from surface water sources and also provides facilities for flood protection and drainage. These are usually relatively large-scale projects (table 30) (1, 189; 6, XII-75).

The importance of low-lift pumps is clear from table 30, although deep tubewells are becoming increasingly important, especially in the drier northwest. About 38,000 low-lift pumps were in operation in the 1979/80 boro season (5, 17).

Almost half of the total irrigated area is now irrigated by modern methods, a substantial increase over the 30 percent about a decade ago (table 31). Deep tubewells have become increasingly important in the last several years. Many small farmers, however, continue to rely on traditional methods such as doons and swing baskets which require only human labor, without need for complicated maintenance and spare parts (62).

Bangladesh's rice yields are among the world's lowest, averaging only about 1.25 tons per hectare, although introduction of high-yielding varieties in the late sixties brought some

Table 30--Bangladesh's irrigated area, by sponsoring organization

Agency	June 1973	June 1978 1/	June 1980 2/	Second plan target
		1,000 hectares		
Bangladesh Water Development Board:				
Flood protection and drainage	1,214	1,821	1,935	2,542
Irrigation	49	65	97	405
Bangladesh Agricultural Development Corporation:				
Low-lift pumps	425	548	599	830
Shallow tubewells	6	24	61	455
Deep tubewells	51	136	245	607
Hand tubewells	--	--	8	36
Subtotal irrigation, BADC	482	708	913	1,928
Private sector irrigation	405	391	473	581
Total irrigation	936	1,163	1,482	2,914

-- = Negligible
1/ End of the first 5-year plan (1973-78).
2/ End of the 2-year plan (1978-80); estimate.
Source: (6, XII-77, 80).

improvement. The present yield level of boro is the highest among all classes of paddy, with a recent average of about 2 tons per hectare. Boro covers slightly over a tenth of the rice area and accounts for about 18 percent of production. Its acreage has been increasing with the expansion of irrigation from low-lift pumps and tubewells. Boro is grown in winter, mostly under controlled irrigation, and responds well to modern technology (6, XII-22,26; 5, 243-4).

Wheat cultivation has increased rapidly in recent years with good potential for further growth. Wheat requires only about a third as much water as rice and its production costs are lower. New wheat varieties are fertilizer responsive and have a much shorter vegetative growth period than the boro rice with which they compete in the dry season (6, XII-26).

Table 31--Bangladesh's irrigated area, by method

Method of irrigation	1969/70	1973/74	1977/78
		1,000 hectares	
Modern methods:			
Power pumps	300	570	554
Tubewells	33	53	127
Subtotal	333	623	681
Traditional methods:			
Swing baskets	42	41	62
Doons 1/	392	344	397
Canals	2/	119	120
Other	2/	169	192
Subtotal	725	673	771
Total	1,058	1,296	1,452
		Percent	
Modern	31	48	47
Traditional	69	52	53

1/ Doons are small wooden conical containers used to lift water from ponds and other water reservoirs for irrigation purposes.
2/ Source gives a combined total of 291,000 hectares for canals and "other."
Sources: (62; 4, 45).

Flood Problems

Flooding is a serious problem in Bangladesh, with 3 to 4 million hectares, or more than a third of the cultivable area, normally flooded annually. The Brahmaputra River usually floods a little earlier than the Ganges, but if the two rivers flood at about the same time and there are heavy rains in the country, the damage is especially severe. These floods carry tremendous amounts of sediment. The sediment load of the three major rivers is estimated to be more than 2 billion tons annually (24, 801; 1, 188).

Flooding in coastal areas presents a special problem of tidal saltwater intrusion. An estimated 12 percent of the cultivated area is exposed to inundation from the sea as a result of high tides or because of tidal waves generated by cyclones. Soil salinization does not appear to be a major problem in the rest of the country. The violent summer rains tend to flush out the salts which accumulate in the soil during irrigation in the preceding dry period (22, 103).

The Bangladesh Water Development Board has completed flood protection and drainage work on almost 2 million hectares. The flood protection plan envisages construction of embankments along major rivers, facilities for drainage of protected areas, and improvement of river channels for quick drainage. The second 5-year plan targeted an additional 600,000 hectares by 1985, to bring the total area serviced by flood protection and drainage to more than 2.5 million hectares (24, 809; 6, XII-80,81).

Water Management and Pricing

The second 5-year plan document listed a number of weaknesses in water management, including: lack of effective coordination among the several agencies involved in the various stages of water resource development, lack of farm-level motivational effort, absence of effective farmers organizations, conflict of interest among the members of the irrigation groups, poor maintenance of irrigation facilities, and inadequate supply of credits and inputs, particularly for small farmers.

Farmers bear only a fraction of the costs of irrigation. For BADC projects, farmers bear much of the recurring costs but only a small portion of the capital cost. The costs of BADC's headquarters and its projects are fully borne by the government. In the case of irrigation facilities under the BWDB, the users pay only nominal charges (6, XII-89).

Annual net benefit per acre from irrigation in the first 5-year plan period (1973-78) was 1,000 to 2,000 taka (U.S. $75 to $150), compared with a cost of furnishing the irrigation facility ranging from roughly 150 to 300 taka (U.S. $11 to $23) per acre, Faaland and Parkinson calculated. They noted a clear case for charging prices that would ensure at least a recovery

of costs and perhaps tap a greater proportion of the resulting increase in production:

> "The increase in charges for the use of water is important from the point of view of production because when water is free there is no incentive or compulsion to use it economically. Many of the tubewells are nowhere near to irrigating the area of land that they could do. Often only a few farmers benefit from them when many others could also be supplied. To charge for water in relation to the cost of supplying it would give an incentive to bring more farmers into the circle of irrigation water in order to meet costs. It is clearly necessary to relate charges to the capacity of the tubewell in order to ensure efficient and economical use of the water. To charge would also help to ensure that pumps and engines were maintained, by building up pressures to obtain value for the money paid" (21, 140).

The second 5-year plan (1980-85) document recognized this problem and noted that:

> "Charging a price for water will make the farmer conscious of the value and importance of water. On the other hand, free water makes him irresponsible in its use. A policy of imposition of water charges to recover at least the operation cost in the beginning and part of the capital cost subsequently will be reinforced during this Plan... It will be the policy of the Government to reduce subsidy on water by gradually increasing the rentals of low lift pumps and deep tubewells and the sale price of shallow tubewells and hand tubewells. Low lift pumps and deep tubewells will also be sold to the users at subsidized prices in the beginning. The rate of subsidy will be gradually reduced by increasing the price. The water rate of gravity irrigation will also be increased" (6, XII-81,92).

Investment in Irrigation

About 31 percent of total development expenditures in the first plan period went to agriculture, rural institutions, and flood control and water resources. This share dropped slightly to an estimated 29 percent in the 2-year plan period (1978-80). The share to flood control and water resources in the first plan period was about 13 percent, declining to 12 percent in the 2-year plan period (6, I-23).

Results of a Bangladesh Government benefit-cost analysis of the different methods of irrigation indicated that irrigated agriculture through low-lift pumps and tubewells was profitable to farmers. Surface irrigation through low-lift pumps had the highest benefit-cost ratio, followed by deep tubewells. Rates of return from gravity flow irrigation systems under BWDB also

were relatively high. Smaller projects with low investment cost per acre appeared to offer higher average benefit-cost ratios than medium and large investment projects. Large-scale gravity irrigation and flood control projects tended to have high unit costs as well as long gestation periods; benefits have generally been much below expectations (6, XII-88,89).

Plans and Prospects

The second 5-year plan (1980-85) cited a growth rate of 6.3 percent per year for the overall agricultural sector. The principal food grains, wheat and rice, are expected to increase at 7.2 percent per year in terms of value added (6.6 percent in terms of output).

Almost a 50-percent increase in food grain production is planned, from the benchmark level of 13.5 million tons to 20 million tons by 1984/85 (table 32). This should provide enough rice and wheat to feed an estimated population of about 100 million at a slightly higher level of consumption per capita than at present and also will permit a small disaster relief contingency. Most of the increase in rice production is projected to result from increased yields through improved water control, and increased use of fertilizer, high-yielding

Table 32--Bangladesh's planned area and production of wheat and rice

Crop	Benchmark 1/		1984/85	
	Area	Production	Area	Production
	1,000 hectares	1,000 tons	1,000 hectares	1,000 tons
Rice:				
Aus	3,155	3,103	3,238	4,830
Aman	5,771	7,422	5,666	9,550
Boro	1,094	2,239	1,214	3,400
Subtotal, rice	10,020	12,764	10,117	17,780
Wheat:				
Irrigated	324	680	809	2,000
Nonirrigated	40	36	202	250
Subtotal, wheat	364	716	1,011	2,250
Total	10,384	13,480	11,129	20,030

1/ Benchmark figures relate to normalized conditions for the base year and thus may differ from actual results in 1979/80.
Source: (6, XII-23,24).

varieties, and improved cultural practices. A substantial increase in wheat area is projected, with some accompanying increase in yields.

A major factor underlying the projected increases in food grain production is the planned expansion of irrigation from the current level of about 1.5 million hectares to almost 3 million hectares by 1984-85. Boro rice and wheat will receive particular attention in the expanded irrigation program. There are no significant areas of virgin land remaining; increased agricultural production must come from further intensification of cropping and introduction of yield increasing measures. The yield increasing effects of irrigation in the dry season are obvious; but, even in the monsoon season, rainfall occasionally is insufficient in critical periods of transplanting and flowering. Supplemental irrigation in such periods significantly increases yields (6, XII-5,12).

Projects are also planned to provide additional protection of coastal areas from saltwater inundation and to improve flood control in affected areas. Low-lift pumps and deep tubewells are scheduled to retain their prominence: 43 percent and 31 percent, respectively, of BADC irrigation facilities. But, a significant expansion in shallow tubewells is planned (see table 30). They are comparatively low cost and have relatively easy operation and maintenance procedures; they also entail fewer organizational problems since the command area is much smaller and fewer farm families are involved. Groundwater surveys are underway to develop more accurate estimates of groundwater resources. The BWDB irrigation program will place more emphasis on small-scale, quick yielding projects (6, XII-83).

Designed capacity of irrigation equipment installed by June 1978 was about 1.77 million hectares, but the area actually irrigated at that time was only about 1.16 million hectares. Some modest improvement in the utilization rate is expected by 1984-85, to perhaps 70 percent. Therefore, the planned design capacity is slightly more than 4 million hectares, to permit an actual irrigated area of almost 3 million hectares (6, XII-87).

Substantially increased investment in agriculture, irrigation, and rural institutions is planned, becoming a third of the public sector financial outlay, compared to 26 percent in the first plan and 28 percent in the 2-year plan. The share going to irrigation and water resources will be about 15 percent, compared with 14.6 percent in the first plan and 10 percent in the 2-year plan (6, XII-6). 18/

18/ Irrigation and water resources in the first plan period actually received about 13 percent, rather than the planned 14.6 percent (6, III-12).

Projected financial outlay for the flood control and water resources development program during the second 5-year plan period is estimated at 30 billion taka (U.S. $1.9 billion) (in 1979-80 prices). About 41 percent of this is allocated to the low-lift pump and tubewell irrigation programs of the BADC.

Slightly over half of the planned outlay will implement BWDB's proposed programs of irrigation, flood control, and drainage. The remaining funds are allocated to support private sector irrigation and for miscellaneous projects such as training, evaluation of completed projects, and contingencies (6, XII-84, 85).

Percentage increases envisaged for food grain production are substantially higher than past achievements. Sharp increases in irrigation and supporting inputs are clearly needed to approach the levels targeted. The acreage irrigated has increased substantially in the last couple of years, especially area affected by modern irrigation.

The plan document outlined an optional supplemental program to produce an additional 2 million tons of food grains over and above the original plan, for a total of 22 million tons by 1984-85. (This option will depend on results of the first 2 years of the plan.) An additional 0.5 million hectares of irrigated land would be required to support this increase, bringing the total irrigated area to almost 3.4 million hectares (6, XII-40a).

The IFPRI study projected a food production level in Bangladesh of slightly over 22 million tons by 1990. The gross irrigated area by then was projected to 4.4 million hectares, assuming an increase in cropping intensity from 140 percent in 1975 to 161 percent in 1990. The IFPRI projected an annual food production growth rate of less than 4 percent for 1975-90, compared with the Bangladesh goal of almost 7 percent per year for the 5-year plan period. Two-thirds of the estimated production increase would come from increased production on irrigated areas, especially new irrigated areas. Most of the remaining increase was projected to result from increased yields on existing rainfed lands (48, 49,86).

Total capital investment for the projected expansion and improvement of irrigation described above was estimated by IFPRI at about $2.2 billion (1975 prices), almost entirely for new irrigation areas (48, 60).

SOUTH KOREA

Intensive land development, including irrigation, drainage, and land consolidation has played a major role in the expansion of

Korean rice production. With irrigation, rice yields are much higher in South Korea than in most of South and Southeast Asia.

Climate

South Korea has cold winters and warm summers. There are about 175 frost-free days in the north and 220 in the south, permitting some double cropping (24, 602). Average annual precipitation is about 1,200 millimeters, ranging from 800 millimeters in parts of Gyeongsang Bug province to 1,400 millimeters along the southern coast. About 60 percent of the rain comes during the summer from July to September. Rainfall is very light in the late fall and winter months. Summer dry periods also occur occasionally during the months of May and June, just when there are great needs for rice seedling nurseries and for transplanting (24, 602; 62).

Surface Water

Average annual runoff in South Korea is estimated at 63 to 70 billion m^3, although a lack of devices for measuring river discharges makes precise estimation difficult. Among the 17 main rivers, the Han River, which passes through Seoul, has been the major supplier of water for irrigation and power (10, 391; 24, 605).

Mountains rise abruptly from much of the eastern coast, and there are many short rivers flowing across the narrow coastal plains. Rivers are longer on the western coast and have built up more extensive flood plains (24, 602).

The more important rivers are the Han, Naktong, Kum, Somjin, and the Yongsan. The Han, draining more than 26,000 square kilometers, is the largest in South Korea. The main agricultural areas of the Han lie in the west and in the southwest portion of the south. The Naktong, draining more than 23,000 square kilometers, lies in the southwest and has good potential for development of irrigation and power. The Kum River drains almost 10,000 square kilometers in the midwestern part of the country. It already has intensive irrigation and flood levees in its lower part, and has potential for power development and flood control in its middle and upper reaches. The Somjin and the Yongsan have some agricultural development potential (24, 605).

Because of the heavy concentration of rainfall in the summer season, rivers show pronounced seasonal variation in flow and are subject to flooding. They also frequently carry high sediment loads from erosion on the steep hillsides (62).

Total annual dependable water supply (surface and groundwater) has been estimated at about 47 billion m^3, a difficult measurement because of extreme seasonal and year-to-year flow variability. This includes an estimated 8.5 billion m^3 of

surface water, based on a flow which was equaled or exceeded 90 percent of the time. This 8.5 billion m^3 is about 14 percent of an accompanying estimate of 63 billion m^3 of annual surface runoff. Irregular seasonal distribution of rainfall and the resulting irregularity in river flow point to the need for storage works to provide irrigation during drought (10, 392).

Groundwater

Use of groundwater for irrigation has not been widely developed, although alluvial flood plains generally yield sufficient shallow groundwater to meet many domestic needs. Annual dependable water supply from groundwater was estimated at about 39 billion m^3. Total water use (from both surface and groundwater) was estimated at almost 14 billion m^3 in 1976, with about 53 percent of this allocated to irrigation, presumably the bulk of it being surface water. Total water demand was projected to increase to about 36 billion m^3 by the year 2000, or about three-fourths the amount judged as dependable water supply (10, 392-3).

Irrigation Methods and Cropping Patterns

South Korea covers about 98,960 square kilometers. Only slightly more than 22 percent, or 2.22 million hectares, was cultivated in 1978: 1.3 million hectares in paddy fields with at least partial irrigation and 0.9 million upland hectares. The area planted in crops in 1978 was 3.0 million hectares, giving a multiple cropping index of 135 percent. This index had been at 142 percent in 1976. Planted area of food crops in 1978 was 2.29 million hectares: 54 percent rice, 25 percent barley, 14 percent pulses, and 7 percent in miscellaneous grains and potatoes. Rice and barley, grown in most areas of the country, are most heavily concentrated in the western and southern coastal areas. Practically all the rice is paddy; there were only 11,000 hectares of upland rice in 1978 (39, 24,32-3).

Irrigation facilities were reported on 1.31 million hectares in 1978, but about 190,000 hectares of this area were only partially irrigated. This represents a decline in partially irrigated area identified in 1974 (table 33). Of the 1.31 million hectares, about 850,000 hectares were double cropped in 1978 (39, 32-3,98). Not all the 1.31 million irrigated hectares are fully irrigated, but the portion that is only partially irrigated has been declining steadily and was less than 200,000 hectares in 1978 (table 34).

Until 1965, comparatively small irrigation projects with high benefit-cost ratios were chosen and each project generally had one source of water supply and its canal. The 1965 plan for Agricultural Water Resources Development for All-Weather Farming proposed new irrigated area of almost 400,000 hectares. This plan included reservoirs, diversion weirs and pumping stations,

and surveys for groundwater resource development. Multifaceted irrigation projects were undertaken from 1965 on which included irrigation, drainage, and land consolidation and reclamation. Severe drought in 1967-68 caused a spurt in groundwater development in the late sixties. Tidal land reclamation (which requires irrigation and drainage) also was undertaken in the southern and western coastal areas. There were an estimated 260,000 hectares of tidal land suitable for reclamation in the midseventies, 60 percent of which could be developed as farmland (33, 262).

Table 33--Types of irrigation facilities in South Korea, 1974

Type of irrigation	Area
	1,000 hectares
Irrigated paddies:	
Pumping plants	101
Reservoirs	405
Weirs	138
Feed canals	10
Infiltration galleries	56
Tubewells	36
Others	304
Subtotal	1,050
Partially irrigated paddies	219
Total paddy field area	1,269

Source: (38, 20-1).

Table 34--South Korean irrigated paddy area

Year	Paddy area with irrigation facilities: Adequately irrigated	Paddy area with irrigation facilities: Partially irrigated	Total
	1,000 hectares		
1960-64, avg.	676	550	1,226
1965-69, avg.	780	507	1,287
1970-74, avg.	1,033	235	1,268
1975	1,065	211	1,276
1976	1,082	208	1,290
1977	1,104	199	1,303
1978	1,121	190	1,311

Source: (39, 98).

Intensive land development has played a major role in the expansion of rice production. Land development in South Korea includes irrigation, drainage, and land consolidation. The latter, sometimes called paddy rearrangement, consists of replacing the uneven pattern of small, irregular plots with larger, level plots in a rectangular pattern of ditches, farm roads, and drains. This paddy rearrangement helps in mechanization, improves water control and drainage, and allows easier access and improved management (62).

With irrigation, rice yields are much higher in South Korea than in most of South and Southeast Asia, reflecting a high level of input use and good management. But, they are still below rice yields in Japan. There remains a significant gap between yields attained on experiment station fields compared with those obtained on farmers fields, indicating a substantial margin for improvement (62).

Two distinct crop cultivation patterns appear in Korean agriculture: paddy fields, usually with full or partial irrigation, producing rice in summer and, where climatic conditions permit, barley in winter; and upland areas with a slightly higher cropping intensity, where barley, wheat, other miscellaneous grains, and summer and winter cash crops are grown. The paddy field pattern occupies 55 to 60 percent of the cultivable area and the nonirrigated upland pattern accounts for 40 to 45 percent (table 35) (62).

Double cropping of rice usually is not possible because of climatic constraints, but a rice-barley rotation is practiced in the southern regions. As earlier maturing varieties and improved cultivation techniques are introduced, the opportunity for double cropping should increase, reaching a projected 60 percent of all paddy land. The peak in labor demand, especially in the rice and barley areas, is a major problem in double cropping. These periodic labor shortages probably are a contributing factor in the fluctuations which have occurred in the multiple cropping index, from almost 145 percent in 1969, declining to 136 in 1973, increasing to 142 in 1976, but declining again to slightly less than 135 in 1978 (62; 39, 32).

The relatively high rate of double cropping partially offsets the annual loss of about 13,000 hectares of cultivable land to urban growth, factories, and roads. Other offsetting factors have been the conversion of upland to paddy and some reclamation of agricultural land from forests and tidal flats. The final result has been a slight increase in the net cultivated area from 2.0 million hectares in 1960 to 2.22 million hectares in 1978, with a peak of 2.32 million hectares in 1968 (62; 39, 32).

Lifting water from an irrigation ditch into a rice paddy by human-powered water wheel in Korea.

Table 35--South Korean crop area, production, and yields, 1975 and 1981 target

Item	Unit	1975	1981
Area cultivated	1,000 ha	2,240	2,335
Paddy field	do.	1,277	1,333
Upland	do.	963	1,002
Production:			
Rice	1,000 tons	4,669	5,472
Barley	do.	1,700	1,875
Wheat	do.	97	283
Yields:			
Rice	Kg/ha	3,830	4,370
Barley	do.	2,390	2,660
Wheat	do.	2,200	2,630
Irrigated paddy fields	1,000 ha	1,072	1,248
Percentage of irrigated area	Pct.	84	94

Source: (62).

Investment in Irrigation

Real investment in agriculture increased by almost 60 percent from 1962-66 to 1967-71 and then more than doubled in the 1972-76 period, compared with the previous 5 years (all in 1970 prices). This reflects growing emphasis on grain production self-sufficiency (62).

Real investment outlays for agriculture, forestry, and fisheries were planned to increase by almost half in the 1977-81 period, compared with 1972-76. 19/ Outlays of 1,341 billion won (U.S. $2.8 billion), 11.8 percent of total outlays for all sectors in 1972-76, were planned to increase to 1,979 billion won (U.S. $4.1 billion), 10.4 percent of the total in 1977-81 (all in 1975 prices). Expenditures on land development (irrigation, drainage, and reclamation) were projected to nearly double, from 359 billion won (U.S. $0.7 billion) in 1972-76 to 600 billion won (U.S. $1.2 billion) in 1977-81. The largest percentage increase in agricultural investment in agriculture was set for mechanization in an apparent attempt to improve labor productivity during the seasonal peak periods that have constrained increases in multiple cropping (62).

19/ Including interest charges during construction, land purchases, research and development, and purchase of used equipment.

Total investment in irrigation construction varied from 10 billion won (U.S. $20 million) to 40 billion won (U.S. $80 million) per year in the first half of the seventies. Until 1970, investments were shared fairly equally between the central government (focusing on large and medium projects) and provincial governments (on small projects--less than 50 hectares). Major projects (aided by external funding) tended to predominate after 1970, while funding for provincial projects declined (62).

Estimates of the probable cost per hectare to bring new land into cultivation or to improve existing land (in 1977 prices) are (62):

	Cost per hectare (U.S. dollars)
Create additional cropland:	
Tidal land reclamation	10,000
Forestland conversion	2,000
Improve existing cropland:	
Irrigation	6,000
Land consolidation	1,200

Plans and Prospects

South Korea's food production can be increased by expanding the area of cropped land through conversion of forest to paddy or upland, reclamation of tidal flats, or through greater cropping intensity on land already cultivated. Food production gains can also be generated by increasing output from existing cropland, through irrigation and paddy rearrangement, greater use of improved high-yielding varieties, intensified application of fertilizer and other inputs, better agricultural practices, and selective mechanization to ease seasonal labor peaks (62).

Tidal land reclamation could create 410,000 hectares of cropland while forestland conversion could account for another 135,000 to 220,000 hectares. Irrigation development could significantly improve 240,000 hectares of existing cropland and land consolidation, or paddy rearrangement, could benefit another 314,000 hectares (62).

Part of the area identified for forestland conversion probably is too steep for other than specialized uses such as orchard development. But, about 110,000 hectares have slopes of less than 19 percent, with much of this area having less than 15-percent slope. Such areas could be developed for upland crop production, assuming precautions are taken to avoid excessive soil erosion. Some constraints identified in upland development

include low fertility and highly acid soils which require special treatment to improve their texture and fertility. Also, these upland areas frequently are in regions of relatively low and variable rainfall during critical parts of the growing season, subject to high variability in crop yields. But, World Bank analyses of such upland reclamation projects suggested that they can be economically viable (62).

Tidal flat soils are generally much more fertile and well adapted to growing a variety of crops. But, tidal land reclamation is expensive and takes a long period for the development of full potential.

The World Bank estimated that 95,000 to 332,000 hectares could be developed, depending on three alternative investment strategies for land and water development, starting from a 1975 base (table 36). Close to 240,000 additional hectares would be

Table 36--Estimated areas of land development in South Korea under three investment strategies, 1977-84 1/

Type of land development	Investment strategy		
	I 2/	II 3/	III 4/
		1,000 hectares	
Improvement:			
Irrigation 5/	38	80	120
Consolidation	40	75	120
Subtotal	78	155	240
Addition:			
Forestland conversion	12	48	60
Tidal land reclamation	5	15	32
Subtotal	17	63	92
Total area to develop	95	218	332

1/ It is assumed that all land improved would be under first crop by 1986 and that full potential would be attained by 1990.
2/ No further investment beyond completion of projects ongoing in 1977. Completion of these projects for land and water development during the fourth 5-year plan period (1977-81) would cost U.S. $600 million, or an average of U.S. $120 million per year (1977 prices).
3/ An annual investment of U.S. $60 million to 1984 in addition to completion of ongoing projects (1977 prices).
4/ An annual investment of U.S. $120 million to 1984 in addition to completion of ongoing projects (1977 prices).
5/ It is assumed that all irrigated area developed would be consolidated.
Source: (62).

improved by 1985 if alternative III is chosen over alternative I. That would cost $120 million more a year than the completion of the ongoing projects investment strategy (62). 20/

The World Bank, combining assumptions on increases in crop area (see table 36), yields, and cropping intensities, made alternative 1990 production estimates for rice, ranging from 5.3 million tons to 6.3 million tons, and wheat and barley, ranging from 1.6 million tons to 2.9 million tons (table 37).

Cropping intensities can be increased through: selective mechanization to ease peak labor demands; improved, quicker maturing varieties; improved irrigation and drainage; and increased domestic price of winter crops relative to rice (62).

The World Bank study assumed given percentage increases above alternative high and low base yields for rice to derive the yield factors used in alternative projections of production. The low base yield for rice was taken as 3.7 tons per hectare, equal to the 1972-75 average but below the 1975 and 1976 yields of 3.8 and 4.3 tons, respectively. The high base yield was set at 4.0 tons per hectare. Average yields were assumed to grow at 1.5 percent per year, thus reaching 4.5 tons per hectare from the low base and 5.0 tons per hectare from the high base by 1990. The high yields were judged to be a somewhat more realistic projection. For barley and wheat, base yields of 2.4 and 2.2 tons per hectare, respectively, were assumed. These were equal to 1975 yields. Barley yields were assumed to increase at 0.9 percent per year and wheat yields at 1 percent (62).

The study projected a 1990 demand of over 5.8 million tons of rice and 4.8 million tons of wheat and barley. The high-yield assumptions for rice would allow self-sufficiency and possibly some exports, although some doubts were expressed concerning the desirability of increased investment to support any substantial level of exports (62).

PHILIPPINES

The Philippine Government plans to develop more than 1.4 million hectares of new irrigated land and rehabilitate about 255,000 hectares of irrigated land by 1987. Rice yields, among the lowest in Asia, are expected to rise significantly as irrigation is combined with such modern inputs as high-yielding varieties.

20/ This level of investment would still be less than the average allocation of U.S. $248 million per year in the fourth 5-year plan period.

Table 37--South Korea's projected food grain production, 1990

Grain and assumption	Land development investment strategy 1/		
	I	II	III
	1,000 tons		
Rice:			
Low yield 2/	5,286	5,474	5,658
High yield 3/	5,871	6,073	6,268
Wheat and barley:			
Assuming an overall cropped intensity of 140 percent	1,568	1,646	1,714
Assuming an overall cropped intensity of 160 percent	2,030	2,780	2,862

1/ See footnotes 2, 3, and 4 of table 36 for explanation of each strategy.
2/ 3.7 tons per hectare increasing to 4.5 tons per hectare in 1990.
3/ 4.0 tons per hectare increasing to 5.0 tons per hectare in 1990.
Source: (62).

Climate

Estimates of average annual rainfall in the Philippines range from about 2,400 millimeters to more than 3,000 millimeters. The precipitation reportedly ranges from a high of more than 5,000 millimeters in Baras on the island of Catanduanes to about 900 millimeters in Agunnetan in the Cagayan Valley. The duration and intensity of rainfall in the Philippines are among the highest in the world. In Baguio, Luzon, 1,168 millimeters of rain were recorded in one 24-hour period in June 1911 (25, 153; 10, 391; 62)

Despite its abundance, rain is unevenly distributed throughout the year, so that crop production frequently is limited by inadequate water supply at critical periods of growth, especially during the dry season. Because of regional variations in topography and the resulting different effects of typhoons, four broad types of seasonal rainfall patterns have been identified: dry season from November to April and wet for the rest of the year; no dry season, with pronounced maximum rain in November to January; seasons not very pronounced, with relatively dry November-April and wet during the rest of the year; and rainfall evenly distributed throughout the year.

North-south running mountain ranges block parts of all the islands from the full effects of either the northeast or southwest monsoon. The frequency of typhoons increases generally from south to north and only southern Mindanao is relatively free from their effects (24, 866; 62).

Lying within the tropics and surrounded by seas, the Philippine Islands have a relatively high temperature everywhere, averaging around 26° to 28° C. annually. Such conditions provide a year-round growing season (62)

Water Resources

The Philippines has more than 400 rivers and 59 natural lakes. Drainage areas of the rivers range from about 40 square kilometers to more than 25,000 square kilometers. The Cagayan River in northern Luzon is estimated to have the biggest river basin, draining 27,500 square kilometers. The largest lake is the Laguna de Bay, also in Luzon, covering 932 square kilometers. The major river basins which have been studied, in addition to the Cagayan, include the Agno, Pampanga, and Bicol in Luzon; Ilog Hilabangan, Panay, and Jalaur in the Visayas; and the Cotabato and Agusan in Mindanao. These basins include almost half of the land under cultivation in the country (24, 868; 51, 308; 20, 15; 36, 41).

The volume of the average annual runoff is estimated at about 323 billion m^3, or an equivalent depth of almost 1,100 millimeters. The annual dependable surface water supply is estimated at about 257 billion m^3, based on flow which is equaled or exceeded 90 percent of the time. Estimated withdrawal in 1975 was almost 30 billion m^3, with 21 billion m^3 used for irrigation. Projected withdrawal at the end of this century is about 113 billion m^3 (10, 391-3).

Reliable estimates of groundwater resources are not available although many areas are believed to have abundant supplies. Groundwater is used principally for industrial and domestic purposes with only limited use in irrigation. The flow of surface streams has been diminishing as forests are denuded, generating a tendency to depend more on reservoirs and also on groundwater resource development (24, 869; 33, 300).

Irrigation Methods and Cropping Patterns

The variable rainfall in the Philippines means that in much of the country no crop is possible in the dry season without irrigation; even in the rainy season, supplemental irrigation frequently helps in increasing yields (24, 868).

There are more than 7,100 islands in the Philippines, with a total area approaching 300,000 square kilometers. Only about 150 of the islands have an area of more than 13 square kilometers, and the 11 largest islands account for 95 percent

of the area. The two largest islands comprise about two-thirds of the area: Luzon, with 106,600 square kilometers, and Mindanao with 96,200 square kilometers (24, 866).

Lowlands, covering 35 percent of the country, range along the coastal fringe, estuary mouths, alluvial plains, and basins lying close to sea level. Uplands cover 65 percent of the country, including rough hill land, small mesas, large table lands, plateaus, piedmonts, mountain valleys, and mountains. These are considered drylands and require different agricultural practices than the wetlands. Estimates of the area suitable for cultivation range from 9.8 million hectares to 11.6 million hectares (24, 866; 33, 299).

Relief, especially slope, is a major factor limiting use of land. Most areas under cultivation have slopes of 0 to 12 percent. Erosion is serious on steeper slopes, a problem compounded by slash and burn agriculture and excessive forest cuttings. Major areas with favorable topography include inland lowlands such as the central plain and the Cagayan Valley in Luzon, the Agusan-Davao lowland and the Cotabato Valley in Mindanao, and the central valley of Panay in the western Visayas. Other agriculturally suitable areas include mostly narrow coastal lowlands and plateaus such as the southwest volcanic upland in Luzon and the Bukidno-Lanao plateau in Mindanao (20, 18).

Drainage in areas under cultivation generally is not a major problem. But 2.5 million hectares are potentially floodable, of which about 10 percent has been afforded flood protection. Another source estimated the total area protected was about 1 million hectares in 1975. The 10-year development program to 1987 called for further substantial flood control protection (51, 319; 33, 300).

About 70 percent of the 9 million hectares under cultivation is used for the production of cereals. Rice and corn are the most important. About 1.2 million hectares are irrigated. Major export crops such as sugar, coconuts, abaca, pineapples, and tobacco take up much of the remaining land (62).

There are three main types of irrigation systems in the Philippines: national irrigation systems (1,000 hectares or more per system) are built, operated, and maintained by the National Irrigation Administration (NIA), and are gravity fed; communal irrigation systems (50 to 500 hectares) generally are also planned and built by the NIA but are operated and maintained by an irrigation association; and pump irrigation systems utilize shallow wells, rivers, and irrigation canals as sources of water (table 38). The service area of individual pump units is small, with the majority serving fewer than 20 hectares (62).

Phillipine field workers transplant paddy rice seedlings on Mindanao Island (FAO photo by F. Mattioli).

New areas of irrigation totaling 307,387 hectares were brought in under the FY 1974-77 development plan: 93,033 hectares of national irrigation projects, 100,990 hectares of communal irrigation projects, and 113,364 hectares of pump irrigation projects, bringing the total irrigated area to 1.15 million hectares by the end of 1977. Much of the irrigated area does not have storage reservoirs so that the availability of irrigation water after the rainy season is sharply limited. Perhaps only a third of the area planted in the rainy season can be irrigated in the dry season (51, 313; 20, 11).

The World Bank Group has financed 11 irrigation projects since 1969 designed to increase Philippine rice production. These include three in central Luzon, four in the Cagayan Valley, one on Mindoro Island, one in the Visayas, and two for smaller systems throughout northern Luzon, the Visayas, and Mindanao. These projects have provided improved irrigation and drainage facilities, better road systems for efficient operation and for marketing of farm products, and stronger supporting services to help farmers adopt new irrigation techniques (62).

The Philippine Government instituted a national program for supervised credit for rice in 1973, the Masagana 99 program, which substantially increased the availability of production credit and technical assistance, especially to small farmers. This has been an effective program, although within the past several years credit coverage has declined because of a high level of arrears in repayment (62).

Table 38--Philippine irrigable areas through 1975

Category	Irrigable area
	Hectares
Additions to national irrigation systems:	
1913-49	97,751
1950-64	189,525
1964-74	134,402
1974/75	40,505
Turned over from Bureau of Lands	21,600
Subtotal, national irrigation systems	483,783
Communal irrigation systems	268,188
Pump programs	202,174
Total	954,145

Source: (33, 300).

Average rice yields in the Philippines have been among the lowest in Asia. The proportion of the rice crop that was irrigated grew from about 19 percent in 1948 to about 45 percent in the early seventies. But yields on irrigated areas averaged only about 2 tons per hectare in the midseventies. The potential for raising yields is greatest on irrigated areas planted with high-yielding varieties, but substantial increases also can be achieved using traditional varieties under irrigation. Better water control, improved extension services, adequate supplies of inputs, and prices acceptable to farmers are essential ingredients for substantial yield improvements (12, 63; 20, 118; 62).

Of the 3.4-percent annual growth in rice output in the Philippines in the 1965-73 period, 1.5 percentage points can be attributed to yield increases resulting from additional fertilizer, 1.2 percentage points to increases in the irrigated area, and a negative 0.3 percentage points to a decrease in the nonirrigated area, according to Herdt. This leaves 1 percentage point as a residual (which includes the contribution to yield of the improved average quality of land arising from a higher proportion of irrigated area). Inadequate water control could account for up to 40 percent of the difference between the apparent potential and actual national yields (29, 3,4).

Water Management and Pricing

Until 1975, irrigation fees on the national irrigation systems were fixed at 25 pesos (U.S. $3.50) per hectare for wet season rice and 35 pesos (U.S. $4.80) for dry season rice. These amounts had been eroded by inflation over the years so that they did not even cover operating and maintenance costs, much less the recovery of any capital expenditure. A new rate formula was introduced in 1975, setting irrigation fees at the equivalent of 100 kilograms of paddy rice per hectare in the wet season and 150 kilograms per hectare in the dry season. At the 1975 government support price for paddy, these new fees equaled 100 and 150 pesos (U.S. $13.80 and $20.70), respectively, in the wet and dry seasons, about four times the previous rates. The government built in a hedge against inflation by specifying the rates in rice equivalents. These new rates cover annual operating and maintenance costs but contribute little toward capital cost recovery. An exception to the uniform rate policy was applied on irrigation systems in central and northern Luzon and the island of Mindoro where the rate was to be gradually raised to 175 kilograms of paddy per hectare in the wet season and 225 kilograms in the dry season (62).

Collection of fees has been a problem, although there has recently been some improvement. The appropriate level of water charges or other benefit taxes is important so that a balance is maintained between reasonable collections for benefits received,

and charges that discourage farmers from participating in irrigation schemes (62).

Investment in Irrigation

The acceleration in government investment in irrigation over the last two decades was induced by the increase in the rate of return to investments in the improvement of land quality, relative to the rate of return to investments in opening new land for cultivation, according to Hayami and Kikuchi. 21/ The spread of high-yielding varieties, which perform better under good irrigation, increased the relative advantage of improving the irrigation infrastructure over opening new land, thereby increasing the incentive for irrigation investment (28, 71).

Despite large initial capital cost, irrigation investment imposes less longrun financial burden on the government than the manipulation of product and input prices, according to one study of the efficiency of price incentives compared to irrigation investment as a means of achieving Philippine food self-sufficiency. Irrigation development is clearly more efficient than rice price support in terms of the social benefit-cost ratio. But, it becomes inferior to a fertilizer subsidy if a high discount rate is applied to a large-scale, high-cost irrigation project. In years of rice shortage, policymakers may rationally decide to adopt shortrun price policies to increase domestic output, despite the longrun inefficiency. It is the rice supply in a shortage year, rather than that expected several years later, that affects social stability and political position (27, 720).

Returns from rehabilitation and improvement of existing systems are high compared with investment costs for new systems. Considerable emphasis is being given, therefore, to such rehabilitation. New small-scale projects have low investment costs per hectare, but relatively high operating costs. The reverse situation exists for large-scale projects when allowance is made for recovering capital costs. But, their current costs are about 50 percent higher than for the small-scale projects (table 39) (62).

One reason why pump systems are cheaper to install is that they are built to lower standards. Individual farmers are responsible for tapping the main canal (which is provided by the pump system) to deliver water to their own fields. Also, no

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21/ Encarnacion quoted a 1974 International Labor Organization study saying that it cost about 1,200 pesos (U.S. $178) in 1973 to bring a hectare under gravity irrigation, compared with a cost of 2,500 to 3,500 pesos (U.S. $370 to $520) to clear and prepare 1 hectare of new land settlement (20, 116).

drainage is provided. In the NIA gravity systems, each 10-hectare block of land is served by water supply canals, drainage systems, and roads which facilitate input and product marketing. NIA systems tend to have more water control and to provide for a better distribution of inputs. Yields are usually 30 to 50 percent higher than with pump systems. Accounting for this difference, the cost of irrigation per unit of output in the large and small schemes is roughly comparable. The small-scale projects, however, have shorter gestation periods and, therefore, produce quicker results (62).

Plans and Prospects

There are about 3.1 million hectares of potential rice areas, according to an NIA topographic map survey. But, it may not be possible to irrigate all of this area because of water resource constraints. The NIA inventory included all existing rice lands plus all other areas with a slope of less than 1 percent, with the exception of areas planted to coconuts (33, 299,300).

The Philippine 10-year development plan (1978-87) targets a 1.4-million hectare increase in irrigated area by 1987. There were already 1.15 million hectares irrigated in 1977, some of which is slated for rehabilitation (table 40). The plan document estimated 3.5 million hectares of potentially irrigable land (51, 313).

Table 39--Philippine investment and operating costs for large- and small-scale irrigation systems

Cost item	Large-scale National Irrigation Administration gravity systems		Small-scale pump system	
	Rehabilitation	New	Electric	Diesel
	1974 U.S. dollars per hectare 1/			
Installation	270	540-810	210	230
Operation and maintenance	13	13	32	34
Recovery of capital 2/	27	68	21	22
Total costs (excluding installation)	40	81	53	56

1/ U.S. $1.00 = 6.8 pesos.
2/ Assuming that the capital cost for the NIA gravity systems is recovered over 50 years; for pump systems, over 10 years. Interest is charged at 10 percent a year for both systems.
Source: (62).

The development plan calls for the allocation of about 24.6 billion pesos or U.S. $3.3 billion (1978 prices) for irrigation, about half of the total planned investment in the water resources development program. Another 14 percent, or 7 billion pesos (U.S. $1 billion), would be allocated to flood control (51, 311).

Rice production grew by about 5 percent per year during 1974-77, after rather poor results in the early seventies. Production was able to meet domestic consumption needs during the crop years of 1975-77. The government exported about 270,000 tons in 1978 and built up reserve stocks. Major factors contributing to substantial increases in production appear to have been continued expansion of irrigated area, use of high-yielding varieties on irrigated and rainfed land, and especially favorable weather. The demand for rice in the Philippines will increase by about 3 percent annually from 1978-90, according to World Bank projections which assumed continued population and income growth. The Philippines should be able to maintain an annual growth rate of 3.7 percent in production, given average weather conditions. With this growth rate, the country could expect to export between 100,000 and 125,000 tons of rice annually by 1985, and possibly 350,000 to 375,000 tons by 1990. Such production increases would require an increase in irrigated harvested area of about 425,000 hectares between 1977 and 1985, and a further increase of about 200,000 hectares

Table 40--Philippine planned rehabilitation and new irrigation construction

Category	1978-87
	1,000 hectares
National irrigation system projects:	
New construction	1,044
Rehabilitation	230
Communal irrigation projects:	
New construction	240
Rehabilitation	25
Pump irrigation projects:	
New construction	133
Total new area for irrigation	1,418
Total area for rehabilitation	255

Source: (51, 313).

between 1985 and 1990. Such increases would be substantially less than those envisioned in the government's 10-year plan (62). The World Bank estimates of increases in irrigated harvested area and in production are of the same order of magnitude as those projected by the 1979 IFPRI study reviewed earlier.

The IFPRI study, based on FAO data, projected an increase of about 418,000 hectares in the area equipped for irrigation and also an increase in the cropping intensity index from 120 to 130, giving an estimated increase of 683,000 hectares in the gross irrigated area in 1990, compared with the 1975 base. This is very close to the 625,000-hectare increase estimated by the World Bank. The IFPRI study, however, has a somewhat higher base estimate of gross irrigated area in 1975, by almost a half million hectares (48, 49).

The IFPRI study projected an average 1975-90 annual growth in food production of about 3.75 percent, close to the World Bank 3.7-percent estimate. About half the food production increase was projected to come from increased production on irrigated areas. Part of this increase would come from new irrigation, part from improvements in existing irrigation facilities, and part from improved yields on existing irrigated areas. The other half of the projected increase in 1990 food production was expected to come from rainfed areas: both from expansion of rainfed areas and from improved yields on existing areas (48, 86).

Total capital investment for the projected expansion and improvement of irrigation was estimated by IFPRI at about U.S. $1.3 billion (1975 prices). This includes new irrigation systems on 418,000 hectares at an estimated cost of U.S. $2,400 per hectare; major improvements on about 280,000 hectares, at U.S. $700 per hectare; and minor improvements on almost 350,000 hectares, at U.S. $300 per hectare (48, 49,55,59,60).

SRI LANKA

A third of Sri Lanka's 1.7 million cultivated hectares are irrigated. Good potential remains for expanding irrigation based on surface water, both through improvement of existing facilities and through new irrigation programs such as the Mahaweli project.

Climate

Sri Lanka is a hot and humid tropical country, although the oceanic effect moderates temperatures. Mean monthly temperatures show only a small variation throughout the year. The highest temperatures are in the districts to the north or northwest of the hills in the central region and in the north-eastern low country, generally in the March-June period (57, 5).

Average annual rainfall is approximately 2,000 millimeters. The 1,900-millimeter isohyet forms the boundary between the wet zone in the southwestern quadrant of the island and the dry zone covering the remaining three-fourths of the country. The dry zone is the area where the average annual rainfall is less than the average annual potential evapotranspiration. Average annual rainfall varies from 5,000 millimeters at certain places in the southwest to less than 1,000 millimeters in the driest zones in the northwest and southeast areas. Thus, even the dry zone receives substantially more rain than the 200 millimeters which technically defines aridity. However, because of the wide fluctuations in annual rainfall in the dry zone--about 30 percent above and below the mean--storage and regulation of runoff is essential for paddy cultivation (25, 122; 10, 391; 24, 151-2).

Rainfall is of three types: monsoonal, convectional, and depressional. Monsoon rain occurs during the two monsoons, southwest and northeast, and accounts for a major part of the annual precipitation. Convectional rain occurs during the intermonsoon seasons, especially in the afternoon and evening, and can occur over most of the island. Depressional rain also occurs mainly in the intermonsoon periods, especially in October and November when it accounts for most of the precipitation (57, 6).

The southwest monsoon occurs in May to September. Rainfall is concentrated especially in the southwest, spreading gradually into the interior. Southwest monsoon rainfall exceeds 2,500 millimeters at some stations in the southwestern hill country (57, 6).

The northeast monsoon season is in December to February. Rainfall is concentrated in the northeast, with most of the rain occurring in December and January (57, 6).

Water Resources

Total annual volume of rainfall over the island is approximately 132 billion m^3. Estimated average annual runoff from all rivers and streams is 43 billion m^3, almost a third of the precipitation volume (24, 150,153).

The island has more than 100 rivers, generally radiating from the central hilly region. Rivers flowing to the west, east, and south are shorter than those flowing to the northwest and northeast. Twenty rivers flow entirely within the wet zone and have a total discharge of over 20 billion m^3. Another 83 rivers flow through the dry zone, carrying an annual flow of almost 23 billion m^3. Among this latter group is the Mahaweli, the largest and longest river. It, alone, has a long-term mean annual flow of 8 to 9 billion m^3. Other large

rivers include the Aruvi, Kala, Kelani, Yan, Deduru, and Walawe. These rivers offer good potential for irrigation, although some interbasin transfer is considered necessary from the wet zone to the dry zone to provide irrigation in the large undeveloped areas (24, 151,153).

Groundwater potential appears to be relatively small although investigations indicate the sedimentary limestone area of the north and northwest has promise (50, 324; 62).

Irrigation Methods and Cropping Patterns

About a fourth of Sri Lanka lies in the wet zone. This region has abundant rain through the year and has rivers to provide surface water for irrigation. Much of the wet zone paddy land is rainfed although part of it is irrigated by small diversions. Drainage is a problem for some paddy fields. Dry zone farmers occupying the northeastern three-fourths of the island have developed a tank water irrigation system because of the seasonal rainfall pattern and the hilly topography. About 6,000 tanks had a storage capacity of about 3 billion m^3 by the midseventies (25, 89,122,124; 54, 124).

About 1.7 million hectares are under cultivation, with a third of the area under irrigation. Approximately 30 percent of the cultivated area is used for paddy cultivation. There has been a rapid diversification of crops during the past 25 years. Rice is the main irrigated crop although other crops such as sugarcane, corn, pulses, and some vegetables are now being irrigated. Tea is produced in the high mountainous areas in the wet zone. Rubber and coconuts are grown in the middle and lower areas, with paddy rice being cultivated primarily in the alluvial areas (25, 123; 54, 124).

Rice is the staple food. The paddy crop is seasonal, with a pattern of cultivation roughly corresponding to the two monsoonal periods. The two main cultivation seasons are the maha (Sept.-Mar.) and the yala (Apr.-Aug.). The "asweddumized" paddy land, or potentially cultivable, is about 630,000 hectares. The sown paddy area in the 1975/76 maha season was about 465,000 hectares, with 425,000 hectares being harvested. About 55 percent was irrigated, with the remainder being rainfed. The sown paddy area in the 1976 yala season was reported at 260,000 hectares, with 210,000 hectares harvested. About 60 percent of the harvested area was under irrigation. The total harvested paddy area in the two seasons was about 635,000 hectares against a reported net harvested area of about 540,000 hectares, implying a paddy cropping index of about 118 percent. The estimated production of 1975/76 maha paddy was roughly 860,000 tons, with an additional 360,000 tons produced in the 1976 yala season (57, 77-79).

The Mahaweli River project is the largest combination of water and land resources development ever undertaken in Sri Lanka. The project envisages diversion of the Mahaweli River to the central, north-central, and northeastern provinces in the dry zone. It proposes utilization of 7.4 billion m^3 of water available in the Mahaweli River and adjoining streams. The project area is about 25,000 square kilometers, or about 38 percent of the island's total surface, with about 55 percent in the dry zone. The project would cover approximately 60 percent of the total irrigable undeveloped land. One of the basic purposes of this river diversion is to permit double cropping of arable land in the dry zone (50, 322,327; 57, 57).

The Mahaweli development plan aims to provide an assured water supply for about 365,000 hectares, including 100,000 hectares already under paddy and sugarcane, and 265,000 hectares of new land. The proposed development originally was to be divided into three phases to be undertaken over a period of 30 years at an estimated overall cost of 6.7 billion rupees (U.S. $1.1 billion) (early seventies prices). The government, new in mid-1977, proposed a sharp acceleration for completion of the project within 5 to 6 years and at an estimated cost of 15 billion rupees (U.S. $2.5 billion) (57, 58,60).

The extent of land under major irrigation works was about 230,000 hectares in the midseventies. The largest of these reservoir projects has an irrigable command area of about 45,000 hectares and a maximum storage of 950 million m^3. Village works, or minor works, consist of small reservoirs and anicut schemes, with each serving some 50 to 100 families. 22/ These small projects are scattered about the country, with the majority of the reservoir projects in the dry zone and the anicut schemes in the wet zone. An estimated 160,000 hectares of paddy were irrigated by such village works in the midseventies. These minor works generally are less costly and have shorter gestation periods than the more capital intensive major projects (26, 46).

Flood control and drainage are problems in some regions. The Mahaweli River development project will institute flood control on more than 500 square kilometers of flood plain in the lower reaches of that river. Other drainage and reclamation projects are also underway, especially in the coastal regions of the south and southwest. These regions have low-lying lands which, if properly drained, are suitable for paddy cultivation in an area where rainfall normally is adequate. In addition to

22/ An anicut is a dam made in a stream for maintaining and regulating irrigation.

Paddy rice in Sri Lanka (FAO photo by J. Bradford).

frequent inundation by floods, some of these areas--estimated at about 70,000 hectares--are affected by salinity and saltwater intrusion during high tides. Where possible, gravity drainage is used, making use of the tidal variation. When the land is very low, however, drainage by pumping becomes necessary (50, 325-7; 26, 46).

Some of the lower basins of major rivers in the wet zone have land with ample supplies of water and only need to be protected from intermittent minor flooding. Major flooding occurs much less frequently, and it is uneconomical to prevent it. About 14,000 hectares were cultivated under the protection of minor flood works in the midseventies. These are relatively low embankments provided with sluices which provide protection at least against minor floods (26, 46).

The government passed a Land Betterment Charges Act in 1976 which empowers it to impose annual charges on irrigation and drainage systems. These charges are to take into account such factors as the amount and dependability of irrigation water, increased agricultural production, cropping intensity, and costs for operation, maintenance, and capital recovery. The government hopes to recover full operating and maintenance costs as well as a portion of the construction expenditures (62).

Plans and Prospects

Most expansion in agricultural land will have to take place in the dry zone because the wet zone already is extensively exploited and is densely populated. Good potential remains for expanding irrigation based on surface water, both through improvement of existing facilities and through new irrigation. Evaluation of the potential for irrigation based on groundwater must await more definitive groundwater surveys (50, 327; 62).

The Mahaweli project will ultimately provide an assured supply of water for year-round irrigation for about 365,000 hectares, but the target date for completion is uncertain. The government places strong emphasis on the project.

The IFPRI study on requirements for accelerating food production in low-income countries by 1990 projected an increase in the area equipped for irrigation from an estimated 400,000 hectares in 1975 to 550,000 hectares by 1990. The gross irrigated area was projected to increase from 540,000 hectares in 1975 to 880,000 hectares in 1990, based on a cropping intensity of 160 percent. Total food production in 1990 was projected at 3.1 million tons, compared with a 1974-76 level of 1.4 million tons. Two-thirds of this increase in production would come from irrigated areas. Of the increase in food production from irrigated areas, about 45 percent would

come from newly irrigated areas, 32 percent from improved irrigated areas, and the remainder from increases in yields on areas already irrigated. A third of the projected increase in food production by 1990 would come from rainfed areas, both by expansion of such areas as well as from increased yields per hectare (48, 49,86).

The total capital investment required for the IFPRI-projected expansion of irrigation was estimated at $422 million in 1975 prices, with more than three-fourths of this allocated for new irrigation (48, 60).

Even though the projected increased investment in irrigation and other inputs would cause food production to increase at a faster rate than during the 1960-75 period, the 1990 production would still fall somewhat short of the consumption projected under the income growth assumptions (48, 26).

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